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Evaluation of factors affecting yield improvement in oilseed rape

by

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Contents

Abstract

Oilseed rape has shown little increase in average commercial yields from 1980 onwards, whereas there has been some progress in improving yields through breeding. The project aimed to identify and evaluate the likely causes of the failure of the commercial crop yields to improve compared to the yield of Recommended List (RL) trials.

Statistical analysis confirmed that yield of oilseed rape from RL trials has increased at approximately 0.033t/ha/year since 1987, whereas there has not been an increase in yield of commercial crops over this time. This has been confirmed even when the RL trial yields are adjusted to represent a similar varietal composition to the national crop in any given year. The difference between the trial and commercial yields increased in the early 1990s, thereafter returning to pre-1990 levels before increasing again.

An increase in disease levels, particularly light leaf spot, is a major factor in accounting for this yield differential. Another important factor is that of sulphur availability. Atmospheric sulphur deposition has declined markedly and, although it is not possible to quantify national yield effect, much of the UK crop is now at high risk of sulphur deficiency. Variation in the proportion of spring rape grown from year to year has made a smaller contribution to the failure of the commercial crop to increase yield. Nitrogen fertiliser is applied at a lower rate now than in the 1980s, but this is only likely to be responsible for a small effect on yield.

Recommendations from this work and others offer the farmer opportunities for implementing disease control strategies and avoidance of sulphur deficiency. In order to achieve closer to the practically attainable oilseed rape yield, as demonstrated by RL trials and to develop an upward trend in national commercial yield, it is necessary to ensure that the messages from this and associated research projects are delivered to farmers, and acted upon.

Summary

In contrast to wheat and barley, a visual inspection of the yield trends indicates that oilseed rape has shown little increase in average commercial yields from 1980 onwards. There has, however, been a regular introduction of new varieties out-yielding their predecessors in Recommended List (RL) trials and there has been an overall increase in yield of variety trials until 1995. Since then, yields have fluctuated widely from season to season. With increasing economic pressures brought about by implementation of the mid term review, progress in improving yields of arable crops in the UK will be necessary to maintain competitiveness. If the industry is to progress, it is necessary to understand the factors contributing to lack of yield improvement and from this provide indications on what measures are necessary to achieve further yield increases.

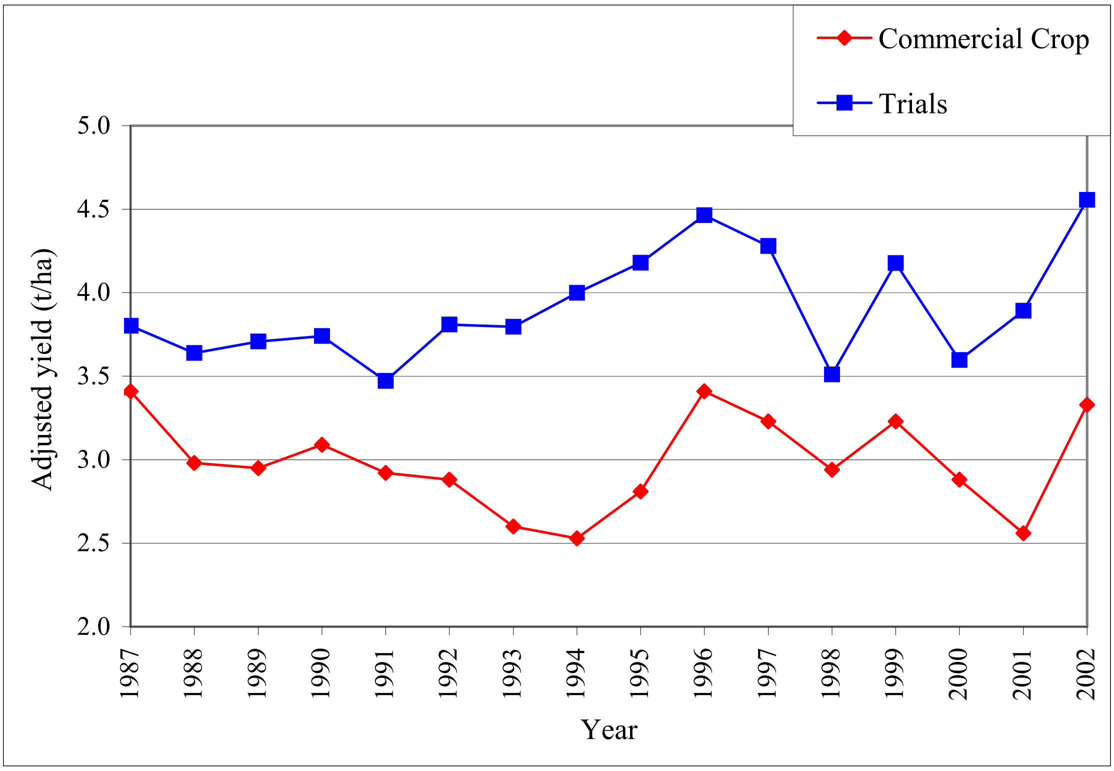
The overall aim of the study was to identify and evaluate the likely causes of the failure of commercial crop yields to improve compared to the yield in RL trials. Several databases holding input data, disease data and yield data exist. These were interrogated and the large amounts of data they contain were linked to help explain differences in yield over the different time periods.

In general, yields in trials are nearly always greater than from commercially grown crops. For oilseed rape, a number of factors may contribute to this, including the yield potential of the selected trial site (soil type, site uniformity, aspect etc.) and more careful management of the trial compared to the field crop, e.g. more timely disease control. Statistical analysis confirms that yield of oilseed rape from RL trials has increased by approximately 0.033t/ha/year since 1987, whereas there has not been an increase in yield of the commercial crop over the same time period. This has been found to occur even when the RL trial yields are adjusted to represent a similar varietal composition to the national commercial crop in any given year.

Rather than the higher yield of trials compared to the commercial crop itself, the extent of the difference between the two, and any changes in this differential over time, are the factors of interest. In the period up to 1996 there seemed to be a fairly convincing increase in the RL trial yields. In striking contrast, for the commercial crop, there was a clear steady decline in mean yields over the seven-year period from 1987 to 1994 (Figure 2.1.1). From 1996 onwards, that variation in mean yield between years was considerably greater than previously. There was however, a fairly consistent pattern of peaks and troughs between the RL trial and commercial crop data. The increase in yield difference between the RL trials and commercial crop was evident during the 1990s, declining in the late 1990s and increasing again since 2000.

The possibility that overall yield response could be affected by a regional bias, with some regions outperforming others, was considered. The importance of the region x year interaction was quantified and estimated to be smaller than the overall between-year variance and it was concluded that yield trends are similar across regions.

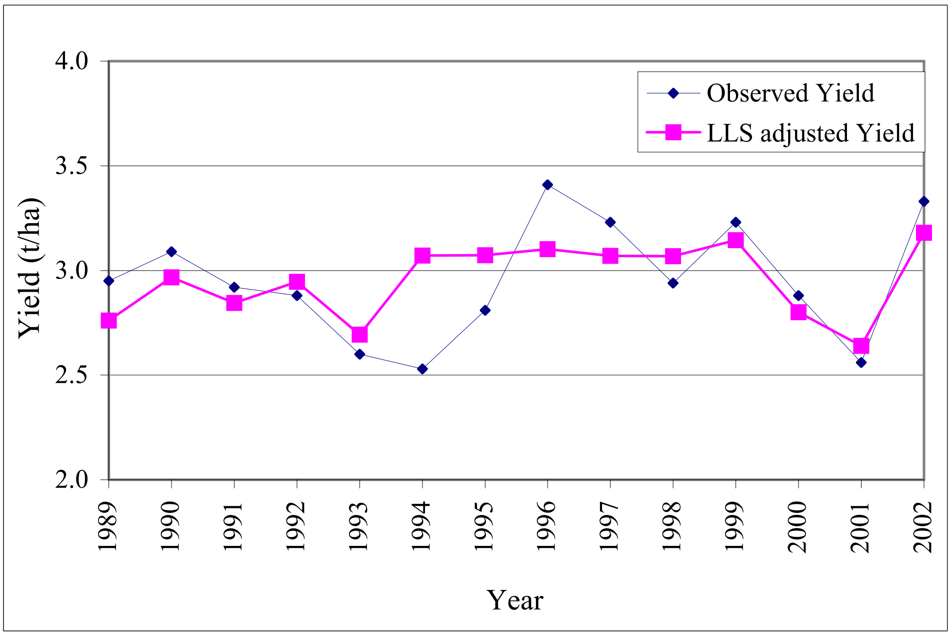
Figure 2.1.1 Mean yields of the commercial crop (Defra) and the adjusted RL Recommended List yields for trials treated with fungicide.



Analysis of the data relating to the contribution of spring oilseed rape to overall oilseed rape area and yield indicated that spring oilseed rape has varied in importance over the years. There was an increase in the level of spring oilseed rape cultivated in the early to mid 1990s, up to around 25% of the total oilseed rape area, coinciding with the greatest difference between the overall mean yield figure and the mean winter oilseed rape yield figure. It is considered that this high proportion of spring rape has had a small impact, possibly in the region of 0.1 t/ha, in constraining the overall mean yield for commercial crops.

Disease was found to have a major influence on the failure of the commercial crop to show a yield response. Statistical analyses of disease figures and yields have shown that much of the variation in yields of commercial crop can be accounted for by the presence of light leaf spot. The major difference in commercial yields and RL yields occurred in the early 1990s. This was associated with a high incidence of light leaf spot, possibly resulting from the widespread use of susceptible varieties and poor control by fungicides. An improvement in disease control coincided with a period of decline in differences between commercial crop and RL trial yields. Statistical analysis to remove the variation associated with light leaf spot resulted in similar general trends of yields of commercial crops to those of the RL trials, indicating that disease incidence has gone some way to explaining the variation in yield within commercial crops (Figure 2.2.3).

Figure 2.2.3 Mean yields of commercial crop, as observed and as adjusted for light leaf spot



Another important factor in preventing the progression of yield is that of sulphur. It is not possible to quantify the contribution of sulphur deficiency to the yield differential between commercial crops and RL trials but it is considered that this factor is likely to be implicated. Sulphur deposition from the atmosphere has declined more rapidly than anticipated in the 1980s and 1990s with the result that at least 50% of crop area is now at high risk of sulphur deficiency and 20% is at moderate risk. Trial results show that yield responses are variable, but are becoming more frequent and were shown to be up to 288% at responsive sites across the UK. Only 25% of the oilseed rape area in the UK is treated with sulphur, and this is at odds with the estimate of 70% of land being at either high or medium risk of sulphur deficiency.

Lower inputs of nitrogen as a consequence of reduced commodity prices, have a much lesser effect on yield of the commercial crop. Nitrogen applications have declined by approximately 87 kg N/ha from 1984 to 1996-2000. However, this relates to only 0.1 t/ha on the response curve.

A number of other factors can be largely discounted as influencing the lack of progress of the yield of the national oilseed rape commercial crop. These include the cultivation of oilseed rape on set-aside, the influence of pests and weeds and the influence of minor diseases such as clubroot and root-based disease. Other factors such as establishment techniques may be involved at local level and seem unlikely to be responsible for a large effect nationally.

In conclusion, the major factors involved in the lack of yield progress with the UK commercial crop can be ranked as disease, sulphur, reduced nitrogen levels and, in certain years, increased spring rape area.

Assuming that improvements in yield potential through breeding continues, it is necessary to ensure that appropriate agronomy maximises the chance of realising variety potential. Considerable research work has been carried out on disease and sulphur topics over the years and recommendations from this work offer the farmer opportunities for implementing disease control strategies and avoidance of sulphur deficiency. In order to achieve closer to the practical potential oilseed rape yield, as demonstrated by RL trials, and to develop an upward trend in national commercial yield, it is necessary to ensure that the messages from this and associated research projects are delivered to farmers and acted upon.

Technical Report

Section 1: Introduction

1.1 Background to cultivation of oilseed rape in the UK

1.1.1 Establishment of oilseed rape as a UK crop

During the 1960s and early 1970s, oilseed rape had only a minor place in British agriculture with a relatively low market value and served as a break crop in intensive cereal rotations. A world protein shortage coincided with the UK's entry to the EEC in 1973, and access to the EEC's support policy for farm prices of oilseeds encouraged an expansion of the area grown (Figure 1.1). The support system at that time was a deficiency payment system, with a target price being fixed annually, representing what was regarded as a fair return to the grower. The difference between the world price and the target price was the deficiency payment paid to the crusher.

Financial support for oilseed rape meant that it was an attractive option for growers and resulted in increases in the oilseed rape area cultivated. This in turn led to pressure on the EC budget and a stabiliser system was introduced from 1981/82. This allowed limited reduction of the target price if the rolling 3 year average exceeded a Maximum Guaranteed Quantity (MGQ) of rapeseed produced in the EU. During the 1980s the market price of rapeseed rose to over £300/t and further expansion of the area grown followed. More stringent price stabilising measures were introduced in 1988/89, with any annual production in excess of the MGQ attracting unlimited reduction in support prices.

1.1.2 Cultivation with direct area payments

In 1989, the EU oilseed regime was found to be non-compliant with GATT rulings and in 1992 a transitional scheme led to the removal of the deficiency payment, and the introduction of a payment to farmers based on area of crop grown. This resulted in the price per tonne falling sharply to as low as £100/t, however area payments increased the average financial return to a level broadly similar to those of pre reform levels. In 1993, wider Common Agriculture Policy reform combined cereal, oilseed and protein (COP) crops under the Arable Payments Scheme, offering area payment to COP crop farmers to compensate for the drop in support prices. The scheme provided the capability to reduce payments if base areas were exceeded. EU/US agreement imposed a further measure to limit EU oilseeds area. This imposed a Maximum Guaranteed Area of oilseeds in the EU distributed across member states according to historic yield. Penalties in area aid were triggered according to national overshoots.

Further reforms of the CAP, Agenda 2000, led to a cut in subsidies with the differential between higher payments for oilseeds compared to cereals being eroded. This was combined with a reduction in market price per tonne from £150/t in 1998 to just over £120/t in 1999/2000. A reduction in cultivated area of oilseed rape followed. Since then prices for rapeseed have improved and prices for cereals have tended to decline, favouring a recovery in area grown.

Prices of rapeseed have altered markedly over the time that oilseed rape has been cultivated in the UK, with a high of £300/t available in the 1980s to a low of around £100/t in the early 1990s. It is evident that these fluctuations and changes in support policy have been strong drivers in influencing the area of oilseed rape grown in the UK. These changes will also have affected the justification of input levels over the years.

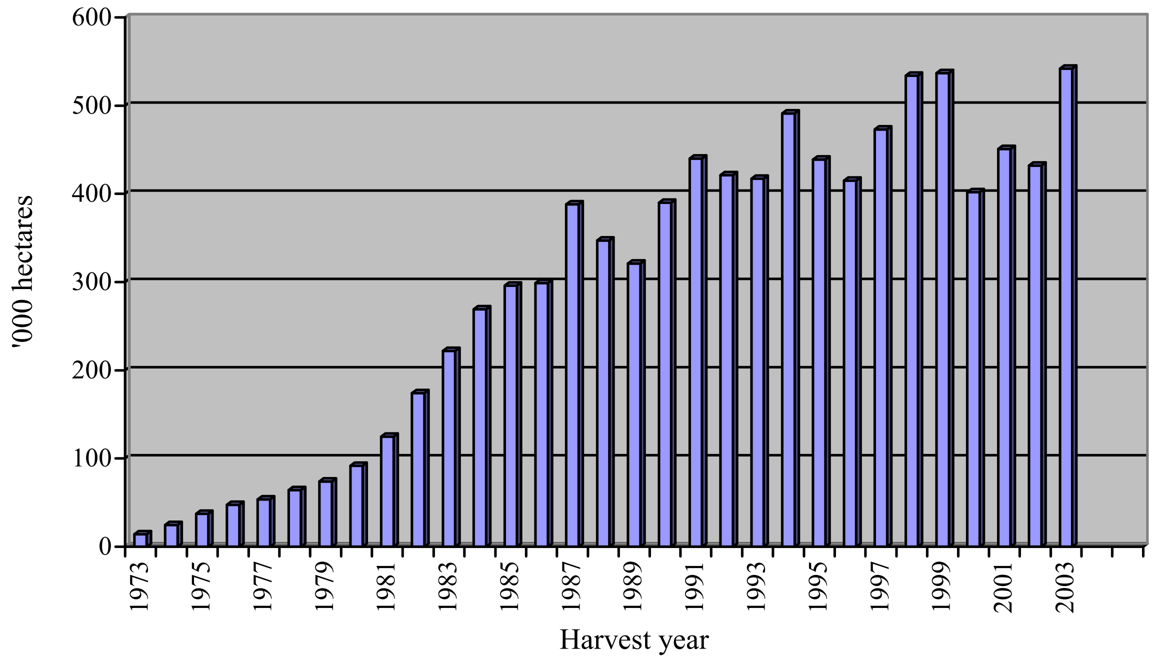
1.1.3 Development of oilseed rape varietal types

There have also been a number of changes in the type of varieties grown. Production of oilseed rape became more attractive in the early 1970s as autumn sown varieties, with higher yield potential than spring sown types, became more available.

In a response to health concerns associated with consumption of high erucic acid rapeseed oil, a major breeding effort resulted in the development of low erucic acid varieties, with the introduction of the variety Jet Neuf. The cultivation of these varieties became mandatory in 1977. Glucosinolates were also recognised as being undesirable compounds due to their limiting effect on inclusion of rapeseed meal in livestock feed. Further significant breeding effort led to the introduction of the first so-called double low variety, Darmor, with low levels of glucosinolates and erucic acid, to the NIAB Recommended List in 1984. Further varieties were developed and grown commercially and at the time of the introduction of direct area payments to farmers in 1992, single low, or high glucosinolate varieties had become ineligible for support. The introduction of these higher quality types had implications for the yield of the crop, with, for example, the replacement of high erucic by low erucic varieties resulting in an estimated 3% reduction in yield which took several years to overcome (Schuster, cited by Bunting, 1986).

In the 1990s, developments in breeding techniques allowed hybrid varieties to become available to the grower, offering the potential for greater yields and vigour. Due to the difficulties of restoring fertility in hybrid breeding programmes, the first commonly available varieties using hybrid technology were variety associations, consisting of a mixture of male sterile and fertility restoring lines. The first such variety Synergy was first recommended in 1996 and achieved a significant share of the market, particularly in the North, for a number of years. Fully restored hybrids quickly followed the introduction of variety associations and by 1997 hybrids were the top yielding varieties in both the Recommended List for winter varieties and Descriptive List for spring varieties. This variety type has continued to perform well and take a significant share of the market, but the newer, conventional, open pollinated varieties are competitive in terms of yield, and hybrids do not now have a clear lead.

Figure 1.1 Area of oilseed rape cultivated in the UK



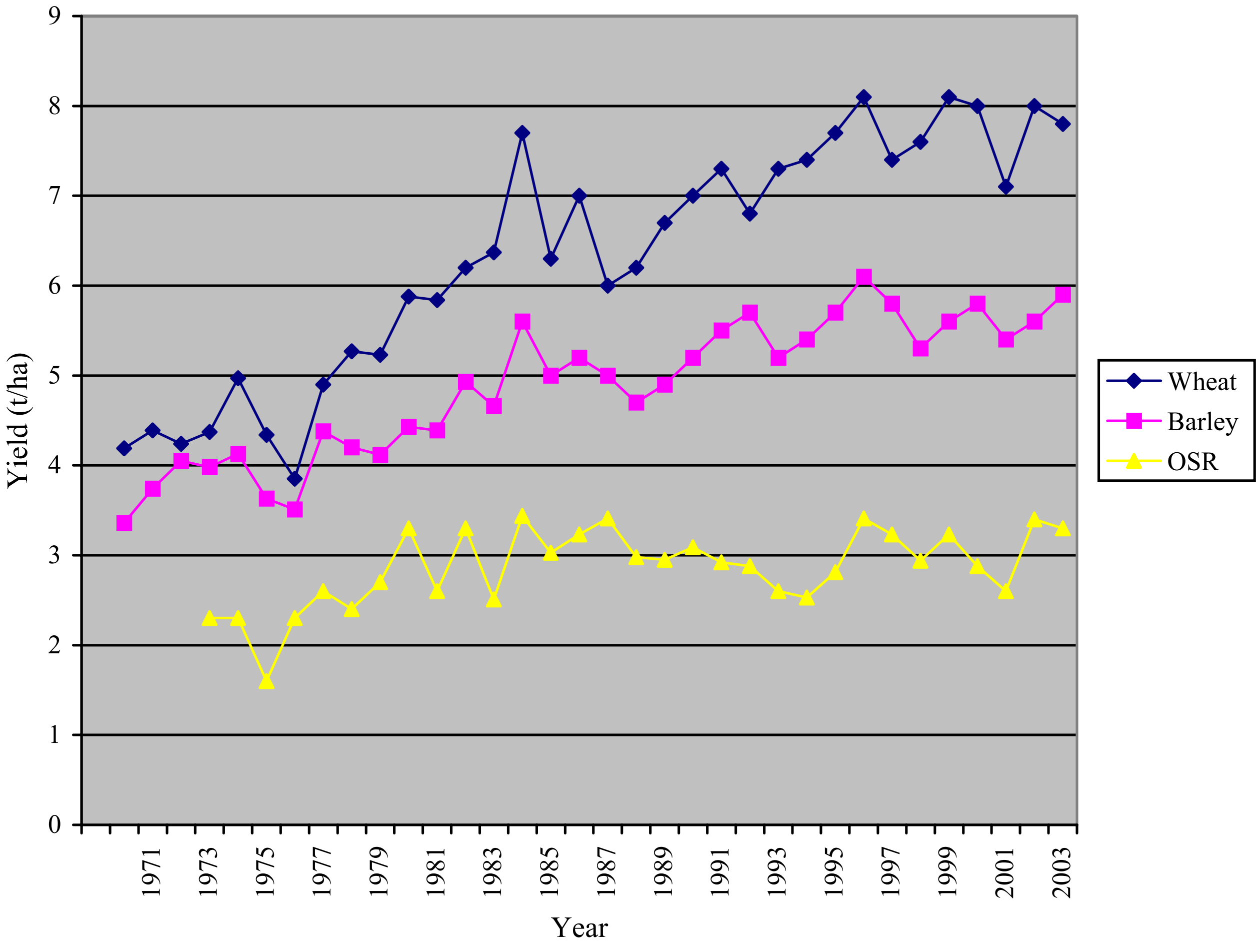
1.2 Yield improvement for combinable crops in the UK.

Average commercial or farm yields of wheat and barley have shown a steady rise over recent years (Figure 1.2). For wheat this yield increase has been equivalent to 0.10 t/ha/year and for barley the increase has been slower at 0.06 t/ha/year since 1980 (Sylvester-Bradley *et al*., 2002). In contrast, oilseed rape has shown little increase in average commercial yields from 1980 onwards. Oilseed rape is a relatively new crop to be grown in the UK and it is reasonable to expect that optimisation of growing techniques and selection of varieties best suited to UK conditions would have resulted in notable and sustained increases in the average farm yield. An important part of both the Recommended List (RL) and National List (NL) variety testing systems is assessment for yield. With the exception of those varieties offering special agronomic or quality advantages, varieties are required to show yield advances compared to others in trials. This has been successful in that there has been a regular introduction of new varieties out-yielding their predecessors in RL trials. Closer examination of the performance of varieties in RL trials (Sylvester-Bradley *et al*. 2002) shows that there has been an overall increase in yield of varieties until 1995. Since then yields have fluctuated widely from season to season.

Thus, there has been progress in improving yields through breeding, as shown by yields in the RL trials, but this has not been translated into an increase in yield of the commercial crop. With the implementation of the mid term review and likely greater reliance on world prices in the future, progress in improving yields of arable crops in the UK will be necessary to maintain competitiveness. On a farm scale, average farm yields appear too low to sustain the present cost structure. Whilst changes to the cost structure of farm businesses may be necessary in any case, it is important to raise yields and at the same time operate within any cross compliances that the new Single Farm Payment support system may require. Unlike previous support, the new support mechanism does not favour oilseed rape over cereals and therefore the lack of progress in improving farm yields of this crop is of particular concern.

If the industry is to progress it is necessary to understand the factors contributing to lack of yield improvement and from this provide indications on what measures are necessary to achieve further yield increases.

Figure 1.2 Average commercial yields of wheat, barley and oilseed rape in the UK



1.3 Physiology of yield

For the analysis of yield determination, the growth and development of oilseed rape can be divided into three main stages; the foundation period, a crop construction period and finally a yield-forming period (Sylvester-Bradley *et al.*, 2002). In the foundation period plants establish, leaves are produced and branches are initiated. Leaves form a rosette as stem extension is minimal during this period. The extent of autumn growth depends on the prevailing weather conditions and the sowing date (Mendham *et al.*, 1981). Net growth usually ceases during the winter months as new leaf expansion barely offsets the senescence and loss of older leaves. Initiation of floral structures is controlled by temperature (vernalization) and photoperiod, and in central England this may take place between November and February (Mendham *et al.*, 1981). In late sown crops, the date of floral initiation can be delayed until the minimum number of leaves has been initiated (Mendham *et al.*, 1981, Tommey and Evans, 1991). The number of leaves initiated prior to floral induction can influence the number of pod bearing branches that are produced as the branches develop from initials in the leaf axils.

In the crop construction period the floral structures develop to form the yield bearing organs. Thus, the flowers themselves first develop and after fertilisation, the seeds are set and the pods form. This phase is associated with rapid canopy growth as leaves expand, the stem extends and branches grow. Rapid growth commences in the spring as temperatures rise. The first flowers appear shortly afterwards, typically in April, and pod formation is usually completed by mid-June (Spink *et al.*, 2002).

The yield-forming period consists of seed growth. By this time, stem dry matter has reached its peak and pod growth is minimal (Mendham *et al.*, 1981). Assimilates for seed filling are derived mostly from current (post-flowering) photosynthesis. Unlike cereals, there is no evidence of net dry matter transfer from stem reserves to seeds (Stokes *et al.*, 1998). At the end of flowering, pods contribute approximately 64% to the total green area (Stokes *et al.*, 1998) and because of their position relative to the leaves, are responsible for the bulk of photosynthesis during the yield-forming period.

It has been argued that the yield of oilseed rape is sink limited because most of the variation in yield is associated with the number of seeds per m^2 (Sylvester-Bradley *et al.*, 2002). However, there is much evidence to show that yield is, to a large extent, determined by events governing radiation capture and photosynthesis towards the end of, and after, flowering. Extensive pre-flowering growth can lead to the establishment of large canopies and high numbers of pods per m^2. However, radiation transmission to the leaf canopy and the earliest formed pods (the lowest pods on the terminal raceme and the pods on the lower branches) is reduced by reflection and absorption by the upper layers of flowers (Fray *et al.*, 1996; Stokes *et al.*, 1998). This can lead to high rates of seed mortality in the middle and lower pod layers (Stokes *et al.*, 1998). In sparser canopies, there is a greater penetration of radiation to the lower pod layers and higher rates of seed survival. These can yield as well or better than denser canopies under the same conditions of incident radiation (Spink *et al*., 2002).

Variation in the efficiency of radiation use within the pod canopy provides a physiological explanation for the effects of plant population and sowing date on yield. HGCA-funded research has shown that low populations (<30 plants per m^2) can out-yield larger populations, provided the plants are uniformly spaced (Spink *et al*., 2002). The smaller populations are able to compensate for the smaller plant numbers by producing more pods per plant and retaining more seeds per pod. Similarly, early sowing (August compared to September) whilst leading to larger canopies at flowering does not result in a larger yield, because the denser canopy leads to greater seed mortality (Mendham *et al*., 1981; Jenkins and Leitch 1986; Spink *et al*., 2002).

The available evidence suggests that in order to maximise yield, crop management should seek to optimise the size of the canopy. The aim is to provide a sufficiently large above-ground biomass to ensure adequate sink capacity (pods per m^2 and seeds per pod), whilst avoiding excessively large canopies that can result in inefficient radiation use and increase the risk of lodging (Sylvester-Bradley *et al*., 2002).

1.4 Possible factors contributing to poor yields of the commercial crop

A number of factors may potentially contribute to the lack of yield improvement of commercially grown oilseed rape, compared to that in RL trials. These can be broadly divided into a number of inter-related categories, which may vary in their influence over different time periods. These relate to the establishment of yield potential through choice of site and variety, and management of the crop to achieve its potential. Variety choice aspects include the possible lack of uptake of new varieties and the variation of spring:winter sown crop ratio as contributing to the overall national yield. Cultivation on low fertility sites may also be a factor. This may include an increase in the proportion of oilseed rape grown in regions less suited to arable crops, or cultivation on set-aside land. Sub-optimal inputs may also be implicated. Inputs may have been reduced as a reaction to economic pressures at different time periods as the economics of the crop varied according to production support, market price, and input costs. Several factors involving disease are likely influences on fulfilling yield potential. Survey data indicates a reduction in use of disease resistant varieties over recent years and this may be having a considerable influence on national disease levels and hence yield.

1.5 Objectives of study

The overall aim of the study was to identify and evaluate the likely causes of the failure of commercial crop yields to improve compared to the yield in RL trials. The intention was to rank these factors according to their effect on yield.

Specific objectives of the study were as follows:

- Verify the initial assumption that the increase of commercial yields has not been in line with that seen in the Recommended List trials.

- Provide an indication of inputs and crop health for commercial crops across the UK over different time periods by analysis of existing databases.

- Determine the possible causes of the mis-match in yields between RL and commercial crops over the same time periods.

- Estimate the relative contribution of the above factors to lack of yield improvement in commercial crops.

1.6 Databases utilised to investigate discrepancies in yield of oilseed rape

There are several databases in existence that hold input data, disease data and yield data relating to oilseed rape over the time period that the crop has been commercially cultivated in the UK. The RL variety testing system provides yields of current varieties across a full range of sites over the period that oilseed rape has been cultivated in the UK. This demonstrates yield under inputs reflecting regional advice for different time periods, but with closer to optimal agronomy, allowing better analysis of the potential of varieties at the time. The Defra-funded disease survey and pesticide survey data collects disease levels and fungicide inputs to commercially grown oilseed rape crops in England and Wales and indicates how disease levels have changed. The British Fertiliser Survey gives information on fertiliser inputs to oilseed rape crops across the UK.

Interrogation of these databases and linking the large amounts of data they contain can be used to help explain differences in yield over the different time periods. The lack of yield progression could be related to more than one factor. To make real progress to improve the yield of oilseed rape it was considered necessary to understand which factors are most important and form a ranking order of these factors. Further, the key factors may differ during different periods of oilseed rape production, for instance the reduction in inputs may have occurred only in recent years. As it is not possible at this stage to ascertain which factors are most influential, the project will test the importance of a full range of factors with the potential to affect yield, including elements relating to disease, fertiliser input and changes in agronomic practices as described above.

Section 2: Investigations

In order to address the four objectives listed in Section 1, a number of investigations were carried out utilising the range of databases available. Autumn sown oilseed rape has taken the predominant share of the total oilseed rape area grown in the UK over its years of cultivation at usually 75 – 85% of the total area. The higher yield from winter sown types lays further emphasis on winter oilseed rape. Therefore this analysis has concentrated on winter oilseed rape. Comparisons and reference to spring oilseed rape are made where appropriate. Data from NIAB/HGCA provided detailed information on both treated and untreated winter oilseed rape recommended list trials across the UK from 1979 (for untreated) and from 1987 (for treated) up to and including 2002. This involved a total of around 65 different varieties over the 24 years. Crop input and disease incidence information was considered where available, but it should be noted that the data for inputs on RL trials were incomplete.

Data relating to the commercially cultivated crop were obtained from Defra for England and Wales and from the Scottish Executive for Scotland. Data on regional oilseed area within England and Wales were available from 1984. From 1995, the England and Wales data were split into separate categories for winter and spring sown crops and data on areas grown on set aside were available from 1993. Information on yield in different regions of England was available from 1997 onwards. For Scotland, data on area of oilseed rape grown were available from 1982, with mean yield from 1984. From 1992, data on area and yield were available on a Scottish regional basis and split into winter and spring crops. To enable valid comparisons, initial analyses were undertaken on commercial data from the Defra census from England and Wales. This represented 80 – 90% of the total UK crop. The smaller portion of the UK crop grown in Scotland was also comprised of both winter and spring types. The limited availability of data divided into the winter and spring crop types for Scotland and even greater limitation for England and Wales meant that it was not valid to combine the data for England and Wales with that for Scotland. Analysis was based on the data from England and Wales with further comparisons with the Scottish crop as appropriate.

The Defra funded oilseed rape disease survey data and pesticide usage survey provided information on disease and pesticide inputs to commercial crops across the survey area of England and Wales. Input data was supplemented by the 'Pesticide Usage in Scotland' data from SASA. The disease survey data also provided an indication of range and proportion of different varieties grown commercially over the years. Disease survey information was available from 1989 onwards. British Fertiliser Survey data provided information on fertiliser inputs to oilseed rape from the 1970s for nitrogen in England and Wales and from 1993 for sulphur in Great Britain.

2.1 Comparison between Recommended List trial yields and commercial crop yields

It is understood that trial yields always tend to be higher than commercially grown crop yields, due to the trials being grown on generally more fertile land, in the better, more uniform, parts of the field with frequent agronomic inspection and generally, a higher level of inputs. These positive factors for yield may be partially offset by the sowing dates of winter oilseed rape trials tending to be later than the commercial crop due to later availability of trial seed, but the balance is still considered to favour the trials. Rather than the higher yield of trials compared to the commercial crop itself, the extent of the difference between the two and any changes in this differential over time, are the factors of interest.

The first investigations sought to determine the extent to which commercial farm yields of oilseed rape (represented by data from the Defra census on commercial crops) are adrift from the higher yields of varieties subject to the year-to-year environmental variation, as represented by the RL trial yields. A direct comparison of the RL and commercial crop is not fair – firstly, in a given year, the RL trials are likely to have newer varieties than those being grown commercially on farms - and secondly, the spread of the RL trials throughout the regions may not reflect the overall spread of the commercial crops. Therefore to make a fair comparison, the RL means should be weighted by both variety and region such that they reflect the composition of the commercial data. Data from NIAB classifies the RL sites into counties, which in turn can be grouped into the Defra census regions and this allowed the data to be weighted by region. Note that Scotland and Wales are also included as separate regions. The region classification used is included in Appendix 1.

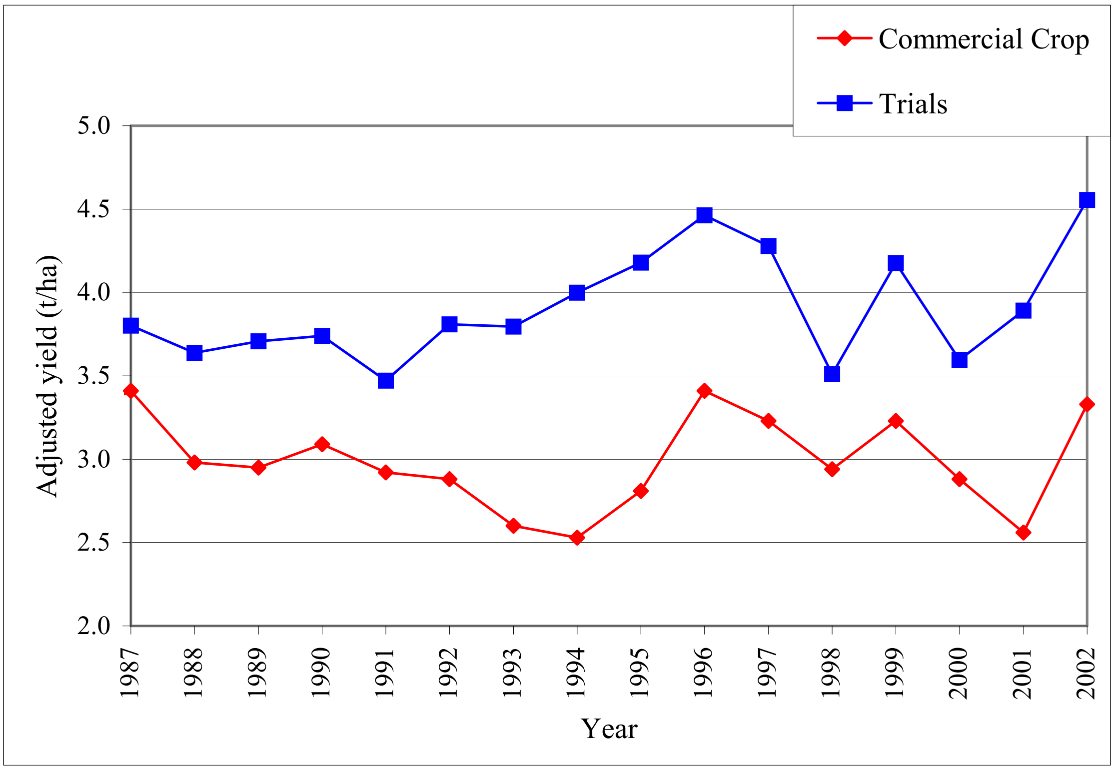
The statistical model used was a linear mixed model (GenStat, 2002), and was fitted to the yield data from the fungicide treated trials in the RL database provided by NIAB. This model allowed for effects of variety, trial, region and year, with an interaction to allow for differences in variety performance between regions. All terms were fitted as random effects, rather than fixed, in order that effects are not over-estimated. Means were obtained for each variety in each region and in each year, therefore representing these overall effects after allowing for the fact that different varieties were represented in different trials.

The information from the census on yield was just a single figure for England and Wales for each year prior to 1997. For the earlier years, information on yields for the separate regions were not available and there was no yield information for separate varieties. However, there was an indication of the area of each variety and the overall oilseed rape crop area grown in each region. Firstly, from the disease survey data, there was a breakdown of the varieties being grown commercially in each year, and secondly, the Defra census data gave the areas of commercial crop grown within each of the regions.

Therefore to obtain an overall mean yield from the RL trials that will be comparable to the overall mean from the census data, the predicted means from the model fitted above were weighted such that the composition matched that of the Defra census mean in terms of the distribution over varieties and regions.

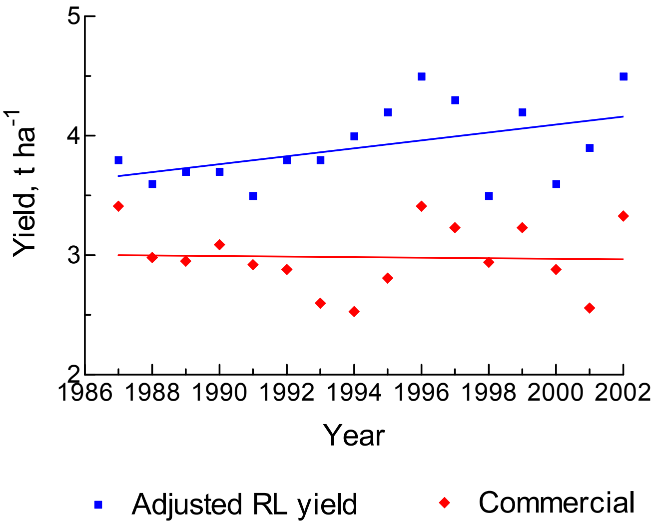
The data presented in Figure 2.1.1 indicate that commercial farm yields have under-performed compared with the RL trials even after adjustment for the effect of variety composition. In the period up to 1996 there seemed to be a fairly convincing increase in the RL trial yields. In striking contrast, for the commercial crop, there was a clear, steady decline in mean yields over the seven-year period from 1987 to 1994. From 1996 onwards, the variation in mean yield between years was considerably greater than previously. There was however a consistent pattern of peaks and troughs between the RL trial and commercial crop data, the only exception being 2001 when the commercial yield was lower than might have been expected based on the RL results. The analysis implies that the general failure of commercial yields to show the same improvement as RL yields is not the result of a lack of commercial uptake of new higher yielding varieties. This provides further support for the conclusion of Sylvester-Bradley *et al*. (2002) on the yields of the commercial crop and RL trials.

Figure 2.1.1 Mean yields of the commercial crop (Defra) and the adjusted RL Recommended List yields for trials treated with fungicide.



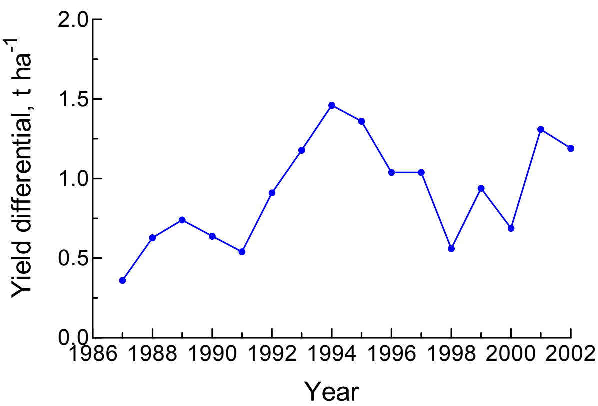
Regression analysis shows that there has been a small increase in mean yield of RL trials since 1987, equivalent to 0.033 t/ha/year. The analysis further confirms that there was no increase in mean yield of the commercial crop (Figure 2.1.2).

Figure 2.1.2 Yields of commercial crops and RL trials adjusted for variety composition. Lines fitted by regression are; commercial crops y = -0.0023x + 7.59, r^2 = 0.002, P = 0.89; adjusted RL y = 0.033x – 62.38, r^2 = 0.22, P = 0.06.



The difference in yield between the RL trials which have been adjusted for variety composition and the commercial crop is shown in Figure 2.1.3. The increase in this differential is evident during the 1990s. The yield difference declined in the late 1990s, but since 2000, the yield difference appears to be increasing again.

Figure 2.1.3 Differential in yield between in RL trials (adjusted for variety composition) and commercial crops. Data are for England and Wales.



2.1.1 The influence of region on yields

With the expansion in oilseed rape area across the UK it was suggested that a regional effect on yield may have become evident, possibly with lower yield being experienced as the crop became established in areas less suited to oilseed rape production.

It is of interest to actually compare how the breakdown of the crop between the regions across the UK as a whole differs for the RL trials and for the commercial crop. The following bar charts (Figures 2.1.4 and 2.1.5) show the regional split of commercial data (by area) as compared with successfully harvested RL trials (by numbers of trials). Comparison of the two charts shows that their composition is quite different. For the commercial data there is little change over time, though in the last three years the proportion in Scotland increased. For the RL trials, there was a very large proportion in Scotland in the few years around 1990 (up to 50%), partly as a result of successful harvests, but in recent years this has fallen to around 20%. Trials in Scotland tend, on average, to be higher yielding so lifting the national RL trial yield average. The potential for exacerbation of the RL trial yields is further justification for excluding the Scottish RL trials data from the analysis.

The possibility that overall yield response could be affected by a regional bias, with some regions outperforming others in some years, was considered. Yields were compared region by region over the years when data were available. Two figures (2.1.6 and 2.1.7) displaying commercial crop yields and RL trials yields for each region, for the years 1997 onwards are presented. The commercial crop figures were obtained direct from Defra and the RL yields were obtained as described above (but also including a region × year interaction in the model) and were weighted approximately by the varieties grown commercially in each year.

In the REML (Restricted Maximum Likelihood) analysis of the RL yields, the importance of the region × year interaction was quantified by assessing the size of its associated variance component. This was estimated at 0.056 (with a standard error of 0.028), smaller than the overall between-year variance, estimated at 0.093 (with standard error 0.043) and certainly visually it seems to be reasonable to conclude that the trends are similar across regions. The commercial crop figures also show similar trends across the regions (Figure 2.1.6), with the exception of the north-west in 1997, however very little OSR was grown in this region therefore little weight should be placed on this apparent anomaly to the general trend. Comparison of the two graphs together shows the trends in yield to be fairly consistent across the regions, apart from the low commercial yield in 2001.

Figure 2.1.4 Distribution of commercial oilseed rape by region (see Appendix 1 for explanation of key).

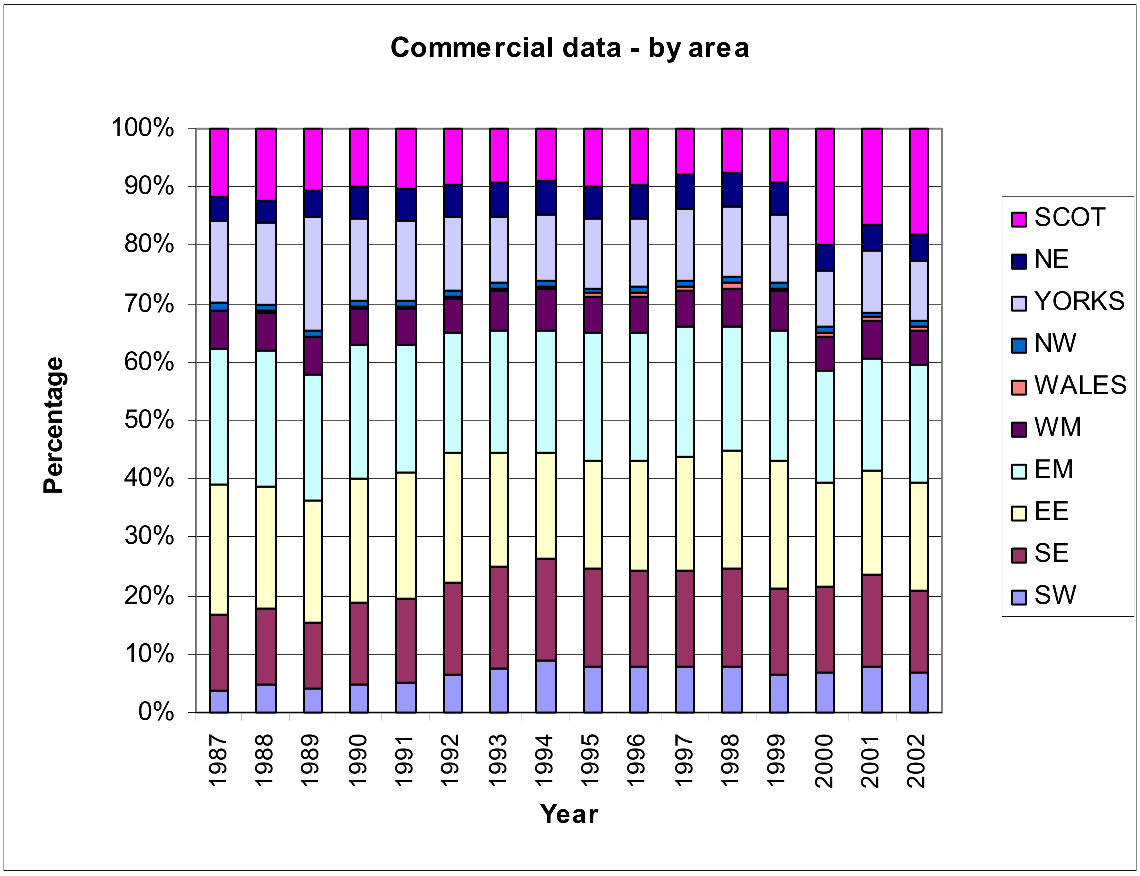


Figure 2.1.5 Distribution of RL trials by region (see Appendix 1 for explanation of key).

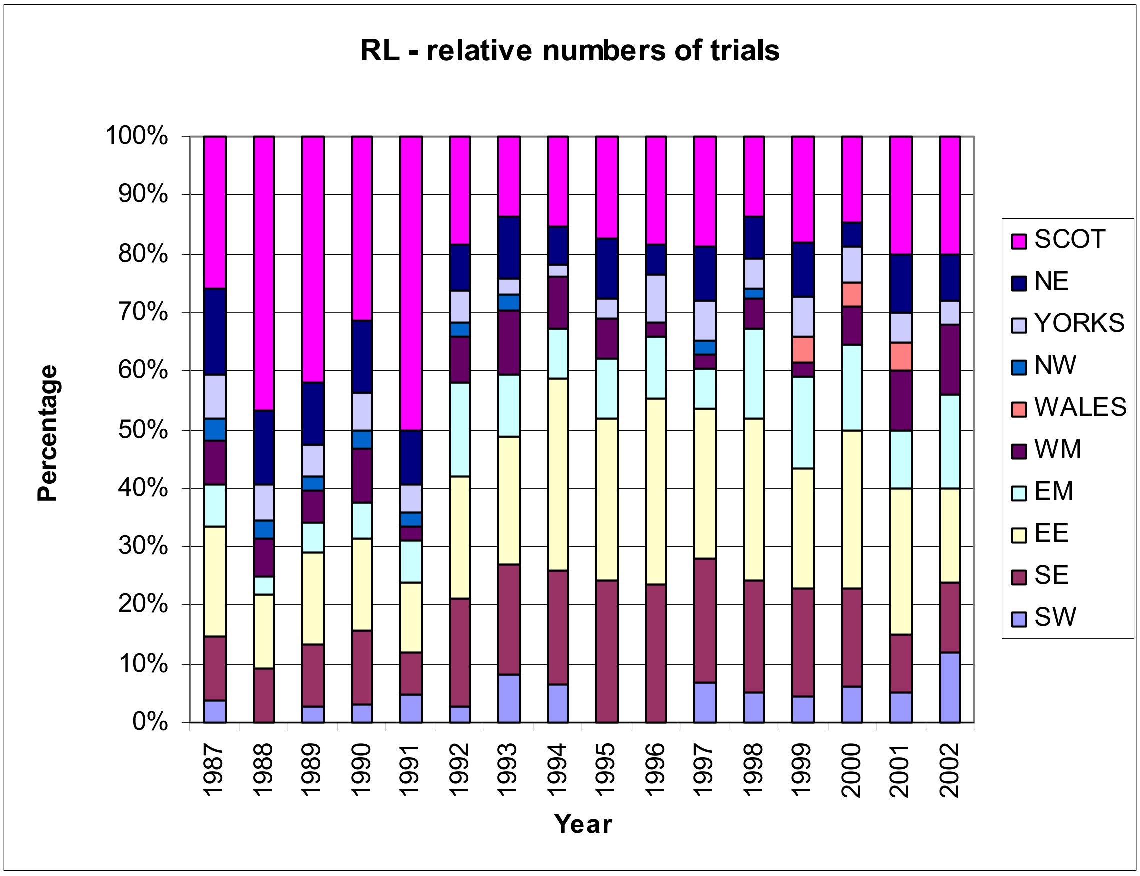


Figure 2.1.6 Commercial crop (Defra) yields by region (see Appendix 1 for explanation of key).

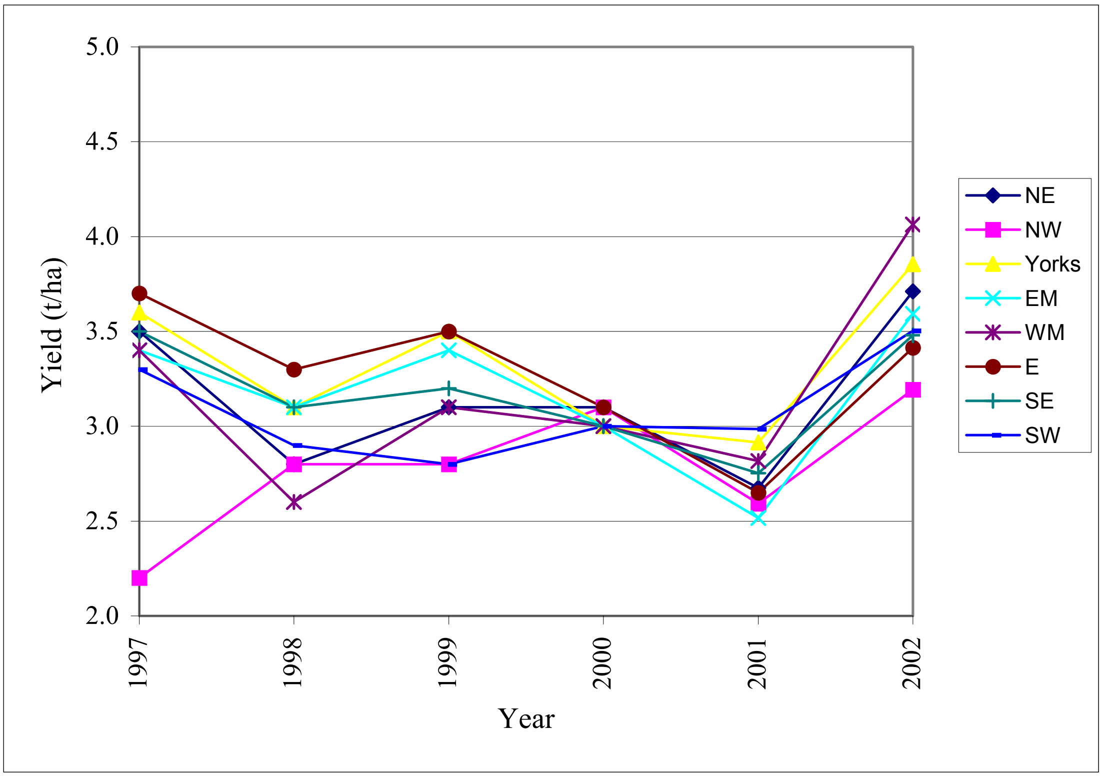
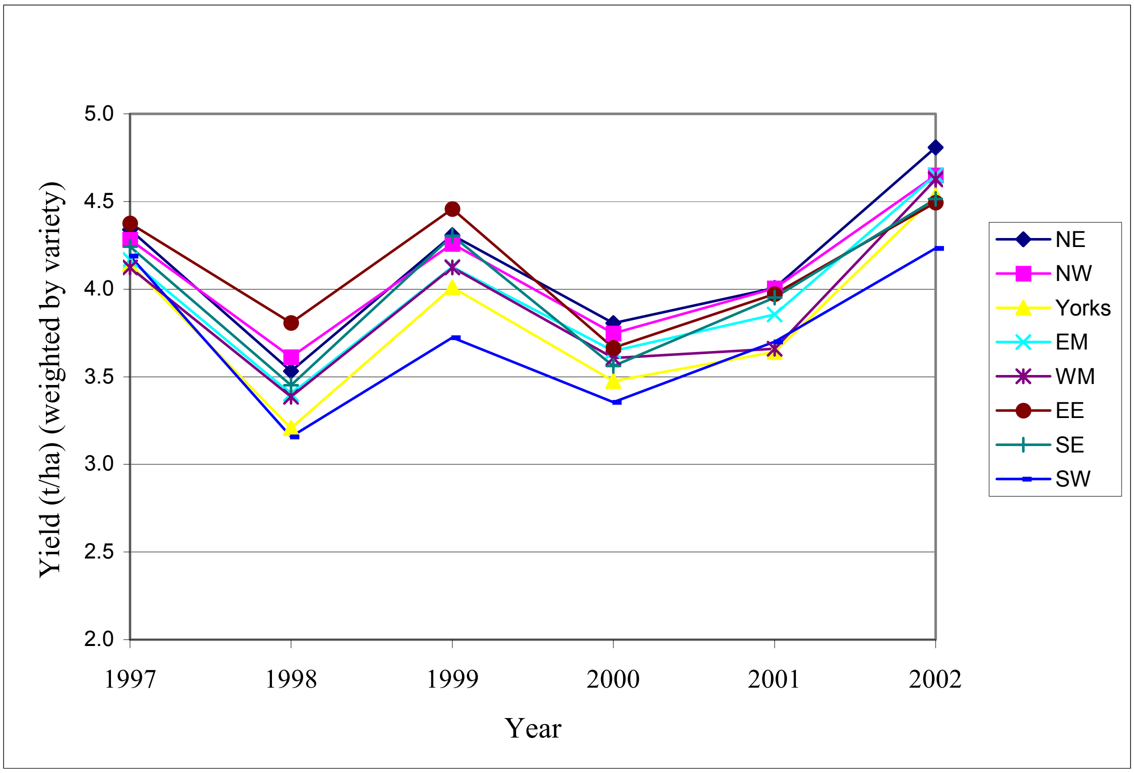
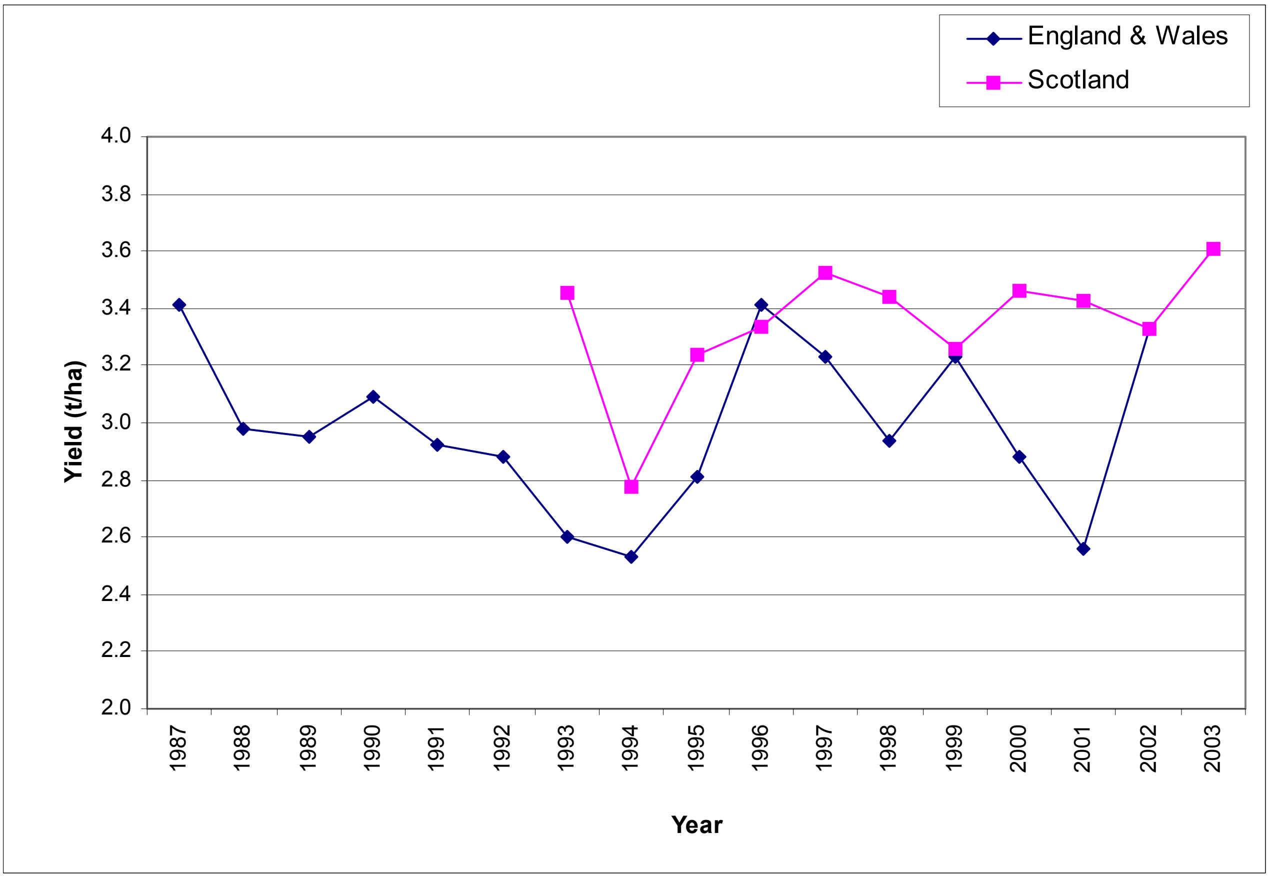


Figure 2.1.7. Mean RL yields from treated trials by region (see Appendix 1 for explanation of key).



To investigate whether trends in commercial yields for Scotland followed that from the rest of the UK, yields from the different areas were compared. Data for yields of the winter oilseed rape crop were available only from 1992, giving a relatively short period for comparison. Commercial yields in Scotland tended to be higher than those in England and Wales (Defra data), but trends over time, in terms of the peaks and troughs, did not fully coincide. For example 2001 was an unusually low yielding year for England and Wales, but not for Scotland (Figure 2.1.8).

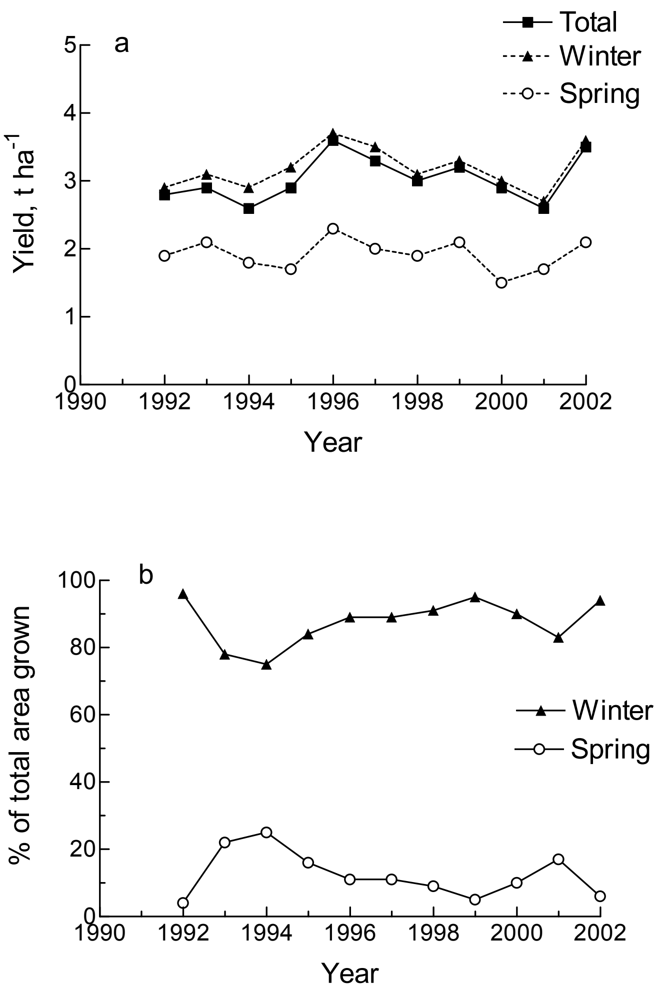
Figure 2.1.8 Commercial mean yields of oilseed rape in Scotland, compared to England and Wales



2.1.2 Winter to spring sown oilseed rape comparison.

The data on the RL trials involves specifically winter oilseed rape. However a small proportion of the commercial crop grown is spring oilseed rape. It was therefore necessary to investigate whether variation in the proportion of the lower yielding spring oilseed rape is responsible for the apparent difference in yield trends between the RL trials and commercial crop yields (Figures 2.1.9a and b). The contribution of spring oilseed rape to the overall oilseed rape area has varied in importance over the years, with an increase in spring sown oilseed rape observed in the early to mid 1990s, up to a proportion of around 25% of the total oilseed rape area in 1994 (Figure 2.1.9b). Thereafter the proportion of spring oilseed rape has been lower with a maximum of 18% in 2001. Analysis of data for yields of winter, spring and total oilseed rape shows that the difference between the total mean yield figure and the mean winter oilseed rape figure was at its greatest in the early 1990s, coinciding with the highest proportion of spring oilseed rape (Fig 2.1.9a). It was considered that the high proportion of spring oilseed rape has had a small impact on overall mean commercial yield, which may be in the region of 0.1 t/ha.

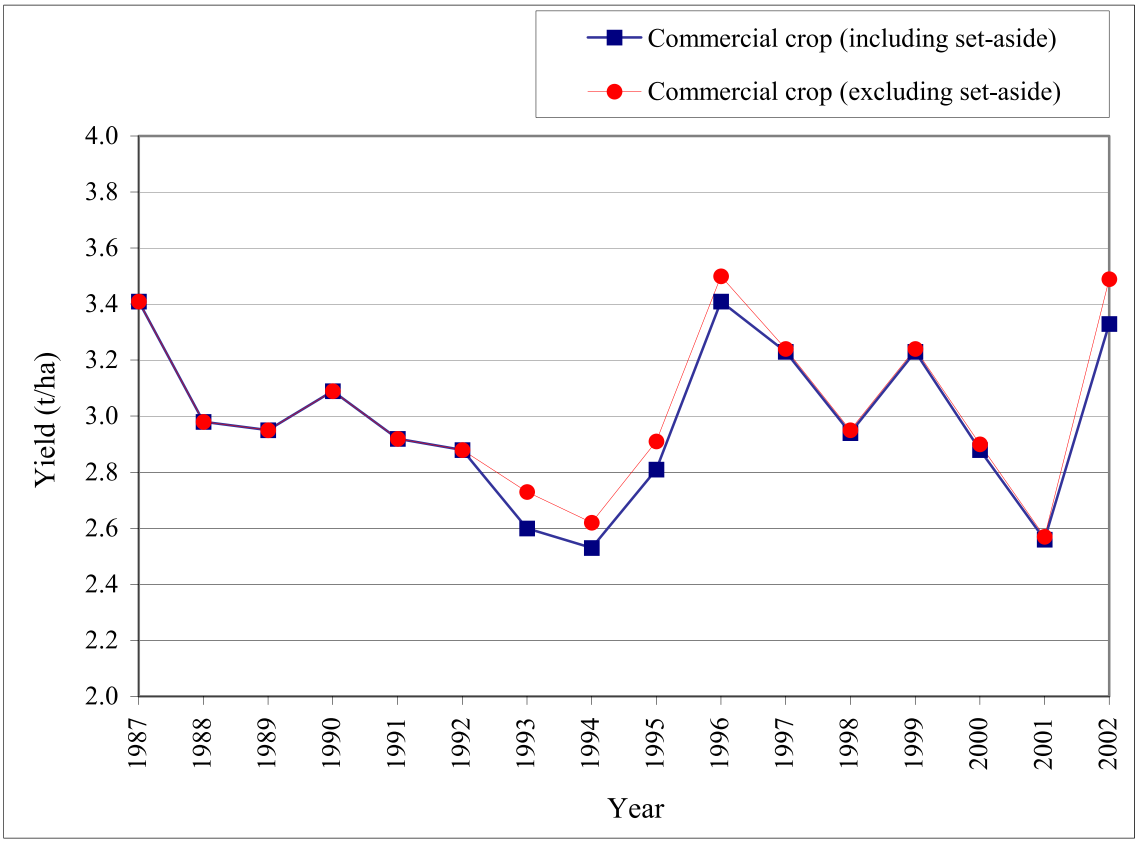
Figure 2.1.9 The yield (a) and the total percentage area grown (b) of commercial winter and spring sown oilseed rape grown on non set-aside land in England.



2.1.3 The influence of using set-aside for cultivation of oilseed rape on yield

One of the hypotheses for the lack of yield improvement in commercial crops is that the increasing use of set-aside for OSR may be contributing to the poor yields. However, if yields including and excluding set-aside are compared, the difference between them is small compared with the overall year-to-year variation in yields (Figure 2.1.8). So although the inclusion of set-aside does affect the picture slightly, it is certainly not one of the main factors contributing to the lack of yield improvement.

Figure 2.1.8 Comparison of commercial crop means yields, including and excluding set-aside



2.2 The influence of disease on yields

Light leaf spot, Phoma stem canker and Alternaria pod spot have been the main diseases of oilseed rape over the past 25 years (Figure 2.2.1). Sclerotinia stem rot levels have generally been low in both the winter and spring crop, with the exception of 1991 when the epidemic was relatively severe in affected crops. Using the Defra-funded disease survey, losses due to all four of the above diseases have been estimated at £27-75 million/annum, with the greatest losses attributed to Phoma stem canker and light leaf spot (see Appendix 2; Fitt *et al.*, 1997).

Various relationships between disease levels and yield losses have been estimated and full details of these can be found in Appendix 2. For light leaf spot it was estimated that for every 10% plants infected with light leaf spot at stem extension (GS 3.3) there was an associated yield loss of 0.14 t/ha (Su *et al.*, 1998). This equates to yield losses from light leaf spot in the UK of £13-50M/annum (Fitt *et al.*, 1997). For Phoma stem canker it was estimated that for every 1% increase in stem canker at seed ripening there was an associated yield loss of 0.01t/ha, equating to an estimated annual loss of £6-42M in the UK (Sansford *et al.*, 1996; Fitt *et al.*, 1997).

Gladders (1998) estimated that for 1% pod area infected with Alternaria pod spot there was a yield loss of 1%, with an estimated economic loss in the UK of £0.02-1.12M/annum (Fitt *et al.*, 1997). Sansford *et al.*

(1996) found that for every 1% increase in the incidence of Sclerotinia (% plants affected) there was a yield loss of 0.016 t/ha, giving an estimated annual loss of income of £0.12-5.4M in the UK (Fitt *et al*., 1997).

These figures show that individually the four main diseases of oilseed rape can cause substantial yield and economic losses within the UK if they are not controlled. However, these diseases often occur together or sequentially within the rape crop and thus have a major influence in the yield potential of commercial crops. Could variations in yields from year to year be explained by changes in disease patterns and could disease explain the differences between trial yields and commercial yields?

2.2.1 Relationships between oilseed rape yields and disease

Data from RL Recommended list trials and commercial crops showed that although yields from commercial crops were lower than those from RL trials, in general the yield trends were similar (Figure 2.1.1). The exceptions were during 1991-1994 and 2001, when RL yields were increasing but commercial yields fell. Could diseases account for these discrepancies?

Data from the Defra-funded survey on oilseed rape reveals a number of key points with possible implications for yield of oilseed rape over the time period the crop has been grown commercially in the UK. As already indicated, light leaf spot and Phoma stem canker have been the diseases most consistently found in commercial crops over the past 25 years (Figure 2.2.1). Alternaria dark pod spot has been present most seasons but has become more apparent over the past eight; severity, however, has been low (Figure 2.2.2). Some diseases have reached unprecedented levels in the last 5 years, e.g., Phoma canker in 2003 (Figure 2.2.1) and powdery mildew on pods in 2003 (Figure 2.2.2).

High disease incidences in 1993, 1994 and 1995 were attributable to Phoma canker in 1993 and light leaf spot in 1994 and 1995 (Figure 2.2.1). These high disease years corresponded to low yield years as indicated by Defra census yield data. The incidence of Phoma stem canker over these three years varied from 42-58%, equivalent to a potential yield loss of 0.42-0.58 t/ha (Sansford *et al*., 1996). The incidence of light leaf spot varied from 20-57%, a potential yield loss of 0.28-0.8 t/ha (Su *et al*., 1998). So together, both light leaf spot and Phoma stem canker could account for potential yield losses in the range 0.86-1.20 t/ha during 1993-1995. The yield differential between RL trials and commercial crops increased from about 0.7 t/ha over the period 1988 – 1991 to 1.5 tha in 1994 and 1995. This increase (0.8 t/ha) is well within the potential yield loss that could be attributed to light leaf spot and Phoma canker.

A high incidence (Figure 2.2.1) of dark pod spot in 1998 corresponded with low yield in RL yield data (and to a lesser extent in the Defra census yield data). However, the average pod area affected was approximately 2%, which would equate to a potential yield loss of 0.05 t/ha (Gladders, 1988), which would not explain a drop in yield of 0.4 – 0.7 t/ha in commercial and RL trials in 1998.

Figure 2.2.1 Incidence of diseases in the summer

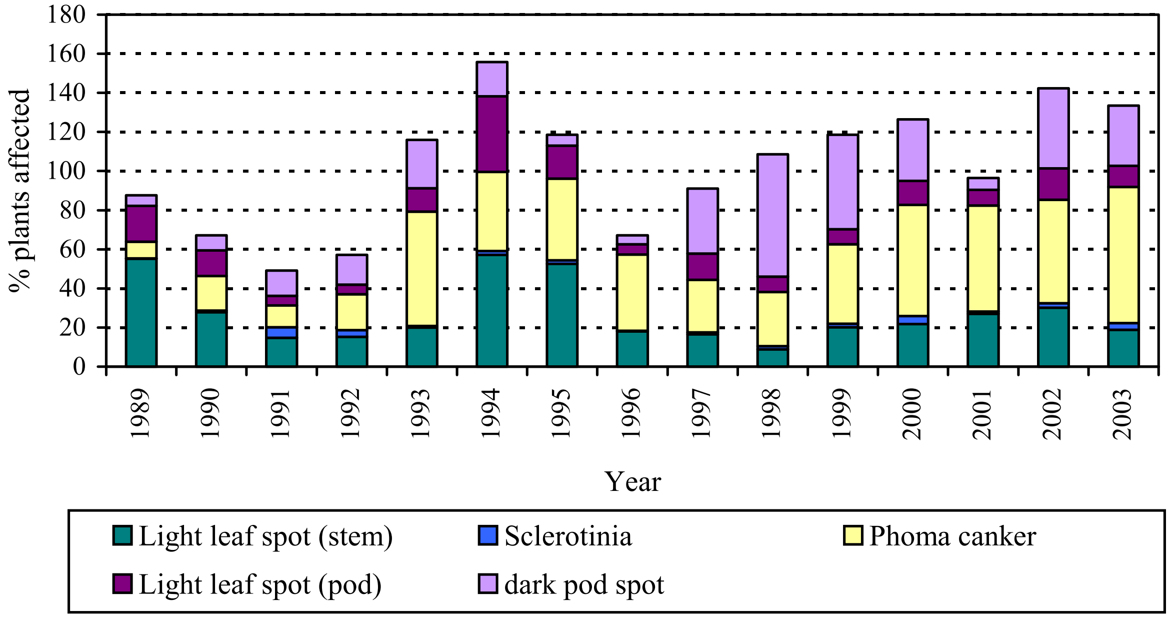
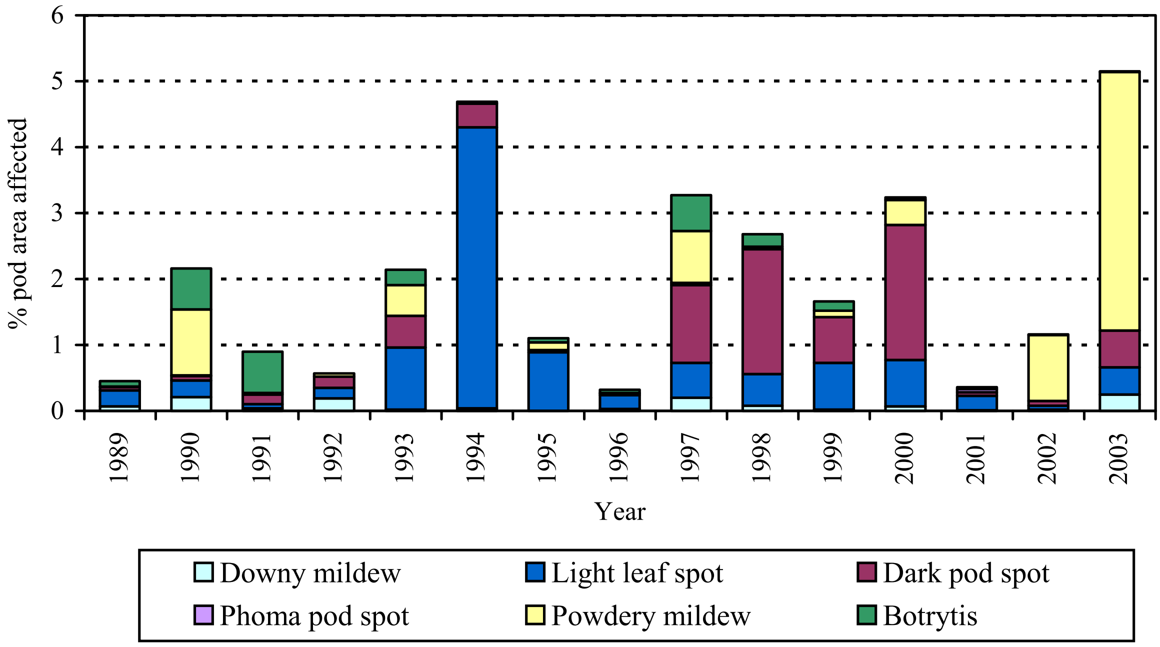


Figure 2.2.2 Total disease severity on the pods



2.2.2 Statistical analysis of disease effects

A visual inspection of the disease levels data from the Defra-funded winter oilseed rape survey discussed above suggested that there may be some important correlations between some of these measurements and the

Defra-published OSR yields for the commercial crop. A number of diseases/assessments were identified as worthy of further investigation. These included:

% pod area – Alternaria, light leaf spot
% stem area – light leaf spot, Sclerotinia, Phoma canker
% plants (pod) – Alternaria, light leaf spot
% plants (stem) – light leaf spot, Sclerotinia, Phoma canker

Of these assessments, the highest correlations with yield were for light leaf spot (4 assessments including severity on stems and pods and incidence on pods and stems) and severity of Phoma canker (Table 2.2.1).

Table 2.2.1 Correlations between disease incidence and yield

Disease/assessment	Correlation with yield
Light leaf spot severity on pods	-0.50
Light leaf spot severity on stems	-0.49
Light leaf spot incidence in summer on pods	-0.38
Light leaf spot incidence in summer on stems	-0.34
Phoma canker severity	-0.29
Alternaria (dark pod spot) incidence	0.25
Phoma canker incidence	-0.21
Sclerotinia incidence	-0.13
Sclerotinia severity	-0.10
Alternaria (dark pod spot) severity	0.01

Multiple regression models were used to assess how much of the seasonal variation in yield could be explained by the disease data. These models took into account relationships between the explanatory variables – eg. 2 variables may each individually have a significant effect on yield, but when included together in the same model, one might be redundant after the other has been taken into account. The procedure of backward elimination (Draper and Smith, 1981) was applied to select the 'most important' variables from the 10 under investigation. A variance ratio of less than 3.0 was used as the criterion for the elimination of variables from the regression model. Of the 10 variables, only 2 were found to be important, accounting for 53% of the variation in yield. These were light leaf spot incidence and severity on the stem (although it should be noted that for the severity, even the worst years showed an average of 3 – 4 % of stem area affected).

If the fitted variables explained all of the year-to-year variation in the yield, then disease-adjusted means should now be constant from year to year. Figure 2.2.3 shows yield means adjusted for the effects of light leaf spot incidence and severity on the stem. The reduction in the peaks and troughs as compared with the raw means indicates that the disease incidence data has gone some way to explaining the variation in yield within commercial crops. In particular, the low yields of 1994 and 1995 can be explained by the bad light leaf spot in those years and the higher yields of 1996 and 1997 by low light leaf spot. However, the subsequent drop in yield in 2000 and 2001 is not explained by this disease data.

It should be stressed that the relationships described can only be thought of as associations – it cannot be asserted that the light leaf spot levels in 1994 were responsible for the low yield, it can only be reported that both factors occurred in that year. It is also worth noting that although some of the other disease variables do not appear useful in explaining the yield in the final model described, they may still be contributory factors. However, the interfaces are restricted by the relatively small number of data points.

2.2.3 Influence of external factors on disease levels

An increase in the percentage of crops grown using varieties susceptible to light leaf spot may have contributed to the increase in diseases observed in 1994, although farm fungicide policy will also have contributed. After the high levels of light leaf spot in 1994/1995, the proportion of crops grown of cultivars susceptible to light leaf spot decreased (Figure 2.2.4). The proportion of susceptible crops remained low until 2000, when the proportion increased to 43%. A similar increase in crops with cultivars susceptible to Phoma occurred and was mainly attributable to the resistance rating for Apex being amended from 6 to 5 for both light leaf spot and Phoma canker. Since 2000, Apex has been less widely grown, instead being replaced with cultivars with higher resistance ratings.

Figure 2.2.3 Mean yields of commercial crop, as observed and as adjusted for light leaf spot

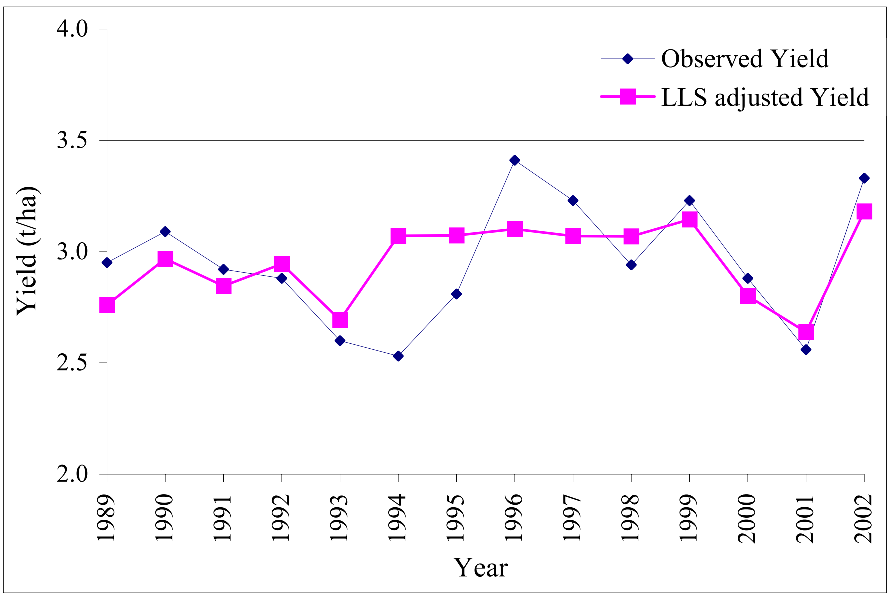
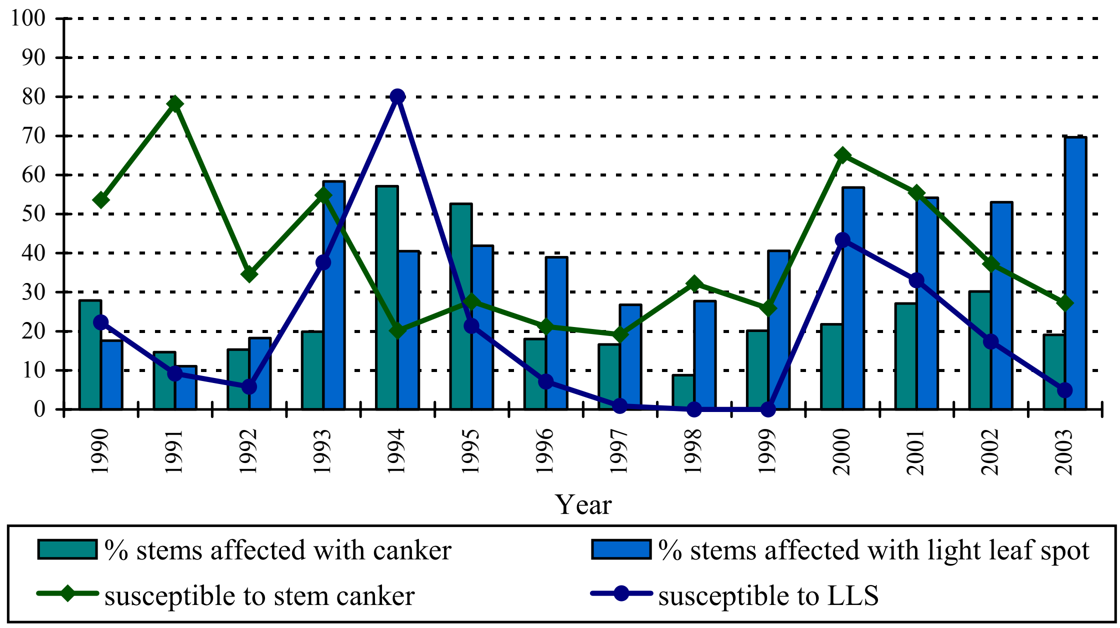
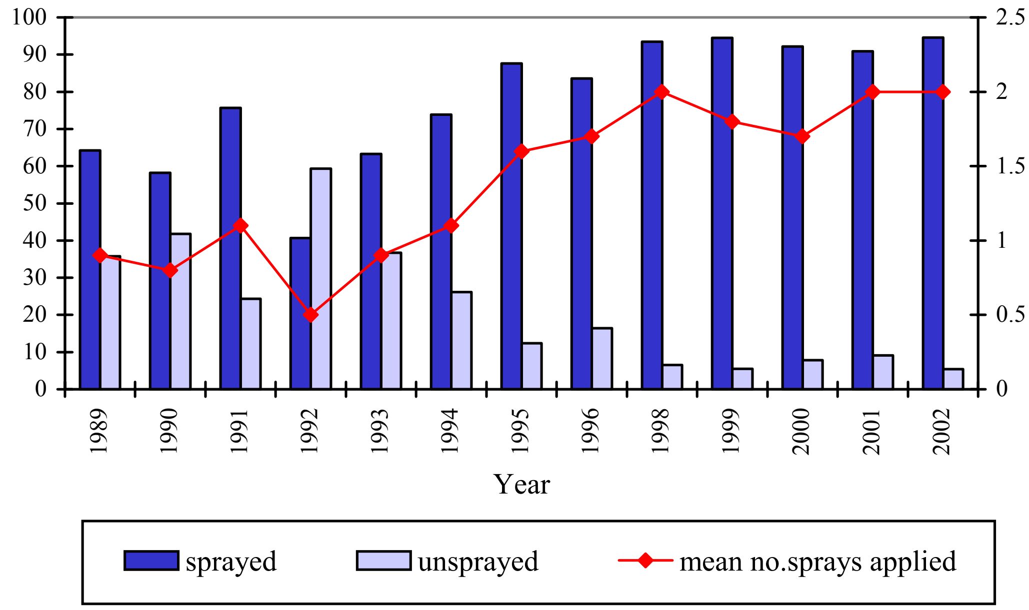


Figure 2.2.4 Stem disease and proportion of crops of cultivar susceptible (HGCA resistance rating <=5) to light leaf spot and Phoma canker



Prior to 1994, the proportion of crops treated with fungicide was low (40 – 75%; Figure 2.2.5). Since then, the proportion has generally increased. After 1995 over 80% of crops have been sprayed (corresponding to the beginning of a two-year increase in yields in commercial crops, see Figure 2.1.1), with over 90% being treated since 1998 (Figure 2.2.5). The mean number of sprays applied has gradually increased, with approximately 2 spays being applied to each crop by 1998. In recent years, the proportion of crops treated with fungicide has not fluctuated according to disease risk shown in Figure 2.2.1.

Figure 2.2.5 Proportion of crops sprayed with fungicide



The actual timing of fungicide sprays has changed over the last 19 years (Figure 2.2.6), largely in response to advice on optimal timing for light leaf spot and Phoma control. Prior to 1995, crops were mostly sprayed in the spring and summer. However, since 1995 the proportion of crops receiving a spray in the autumn/winter has gradually increased, initially in response to the light leaf spot epidemic of 1994. The proportion of crops receiving a spray at flowering increased from 1992 in response to a perceived increased risk from Sclerotinia stem rot following high levels in 1991, but has since leveled out (Figure 2.2.6). The total amount of active ingredient applied to crops decreased between 1992 and 1994, and has remained at these lower levels since (Figure 2.2.7). These data suggest fewer sprays being applied (although Figure 2.2.6 does not support this), that lower doses are being applied, or that the use of products with lower application rates was increased. There appears to be little relationship between inputs and disease risk. For example comparing disease levels in 1994 and 1996 (high and low disease years respectively; Figure 2.2.1) with inputs in 1994 and 1996 (Figure 2.2.7) show little correlation.

Figure 2.2.6 Timing of fungicide applications

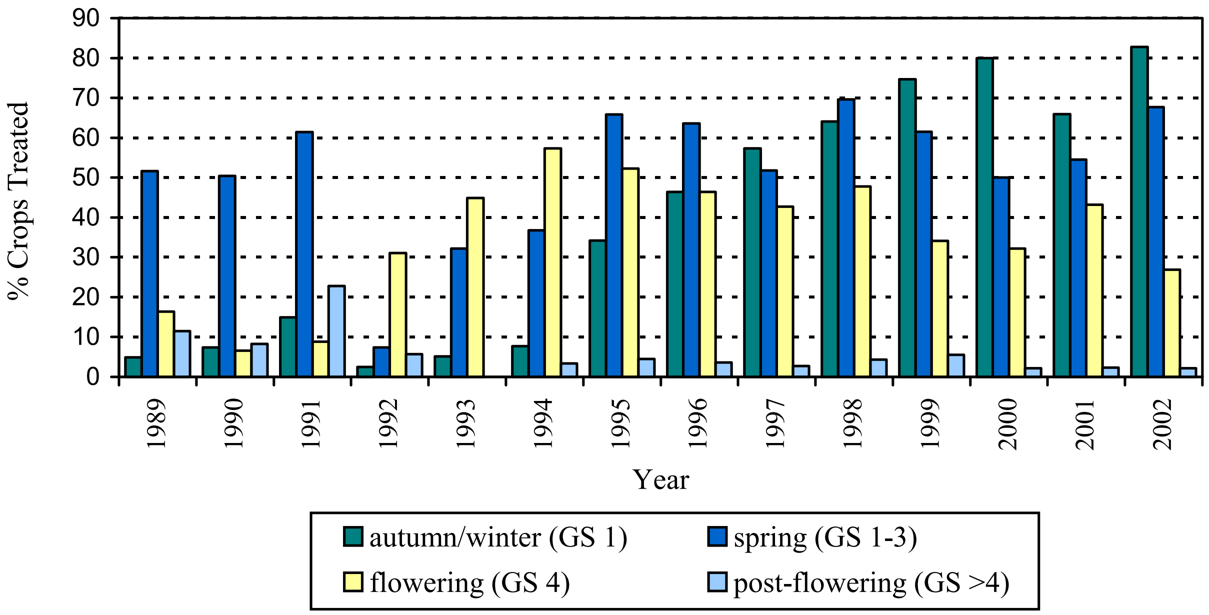
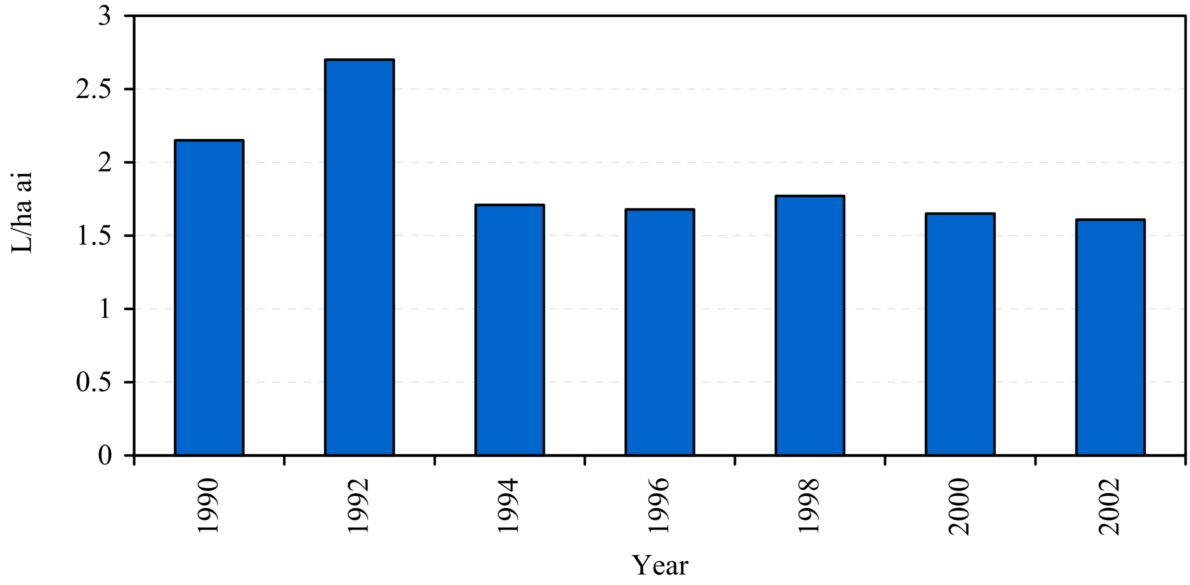


Figure 2.2.7 Mean fungicide inputs (L/ha active ingredient) (from Pesticide Usage survey data)



Light leaf spot and Phoma stem canker are considered the most important diseases of oilseed in the UK. Analyses of the Defra-funded survey data (Appendix 2, Figure 1) agree that the highest yield losses are attributable to light leaf spot and Phoma canker. Research has shown that fungicide treatment in the autumn is important for control of both light leaf spot and Phoma canker and this message has been taken up by the industry as highlighted by Figure 2.2.6, showing a steady rise in autumn fungicide application since 1994 after the light leaf spot epidemic and increase in Phoma incidence at this time. Sclerotinia stem rot is a more sporadic disease, but is also perceived as significant in warranting fungicide inputs even though the relatively high incidence in the epidemic of 1991 has not been repeated since. The ideal time to apply fungicides for Sclerotinia control is early to mid flowering and Figure 2.2.6 above shows the extent of treatment at this timing. Analysis of Defra-funded survey data estimate that Sclerotinia stem rot has contributed to yield loss in some years (Appendix 2, Figure 1), although to a much lesser extent than either Phoma or light leaf spot. Alternaria dark leaf and pod spot has the potential to cause high yield losses, and in the 1980s was considered the most important disease of oilseed. Control is achieved by using seed treatments and post-flowering fungicide treatments. This is also sporadic and is no longer considered such a significant problem. Figure 2.2.6 shows that only a very small proportion of crops received treatment post-flowering for control of Alternaria. Analyses of survey data estimate that Alternaria dark pod spot has contributed to some extent to yield loss in recent years, particularly in 1998 and 2000 (Appendix 2, Figure 1). Investigations for this project support the assessment that light leaf spot and Phoma canker are the two most important diseases in terms of yield loss, as the highest correlations found with yield were for these two diseases.

2.2.4 Conclusion of disease *versus* yields of oilseed rape

Statistical analyses of disease figures and yields have shown that much of the variation in yields of commercial crops can be accounted for by the presence of light leaf spot. The time when a major deviation in commercial yields and the adjusted RL yield occurred was in the early 1990s. The analysis carried out here indicates that this deviation is associated with a high incidence of light leaf spot, possibly resulting from the widespread use of susceptible varieties and poor control by fungicides. By removing the variation associated with light leaf spot the general trends in yields of commercial crops are similar to those of the RL trials. Yields of commercial trials are, however, still lower than those of the RL trials. This would be as expected however, as disease control in RL trials is generally good with trials being subjected to more regular inspections by agronomists experienced in control of disease and tend to receive more timely and higher levels of fungicide application compared with commercial crops.

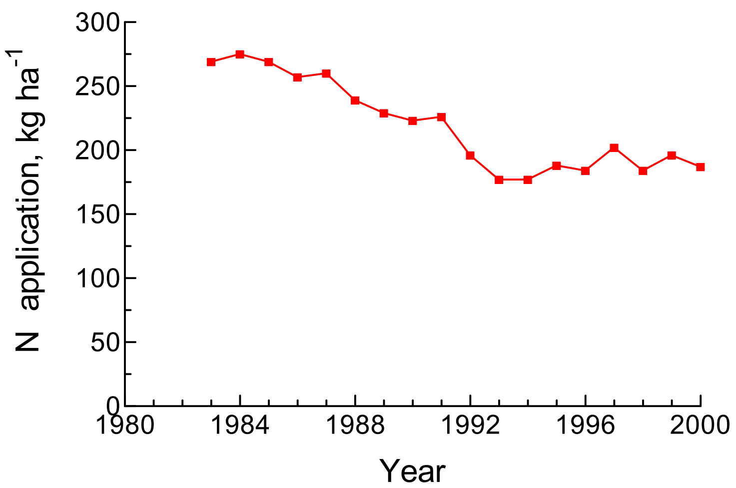
2.3 Effects of fertiliser levels

2.3.1 Relationship between Nitrogen application and yield

2.3.1.1. Nitrogen fertiliser use

The total amount of nitrogen fertiliser applied to commercially grown oilseed rape crops decreased steadily between 1984 and 1994 (Figure 2.3.1). Since then applications have remained relatively constant. In 1984 the average rate applied was 280 kg/ha. Between 1996 and 2000 the rate was 193 kg/ha (Anon, 2001). The figures are averaged for all oilseed rape crops and include both winter and spring varieties.

Figure 2.3.1 Mean rates of nitrogen application to commercial oilseed rape crops in England and Wales



Before 1992 the reduction was mostly associated with a decrease in the amount of autumn applied nitrogen. This involved both fewer crops receiving autumn nitrogen, and where it was used, a slightly lower rate of application. The percentage of crops in England and Wales receiving autumn nitrogen declined from approximately 87 to 50% and the average rate of application fell from 52 to about 45 kg/ha. From 1992 onwards these trends continued so that by 2000, 39% of crops in England and Wales and 55% of crops in Scotland received some autumn nitrogen. The average rate of application in 2000 was 43 kg/ha for England and Wales and 38 kg/ha for Scotland. In England and Wales, the lowest rate of autumn nitrogen was in 1997 when 36 kg/ha was applied. From 1997 to 2000 it rose again to 43 kg/ha (Anon., 2001).

The reduction in the total amount of nitrogen applied to crops was in response to revised fertiliser recommendations. The introduction of the Arable Area Payment Scheme (AAPS) led to changes in the economics of oilseed rape production and the need to reduce nitrogen inputs to achieve an economic optimum rather than a maximal yield response of the crop. During the mid 1990s there was also an increase in the proportion of spring-sown crops. This contributed to the lower average nitrogen application rate because spring-sown crops have a significantly lower nitrogen requirement than winter crops. Between 1996 and 2000 the average nitrogen rate for winter crops was 208 kg/ha whilst that for spring crops was 87 kg/ha (Anon., 2001).

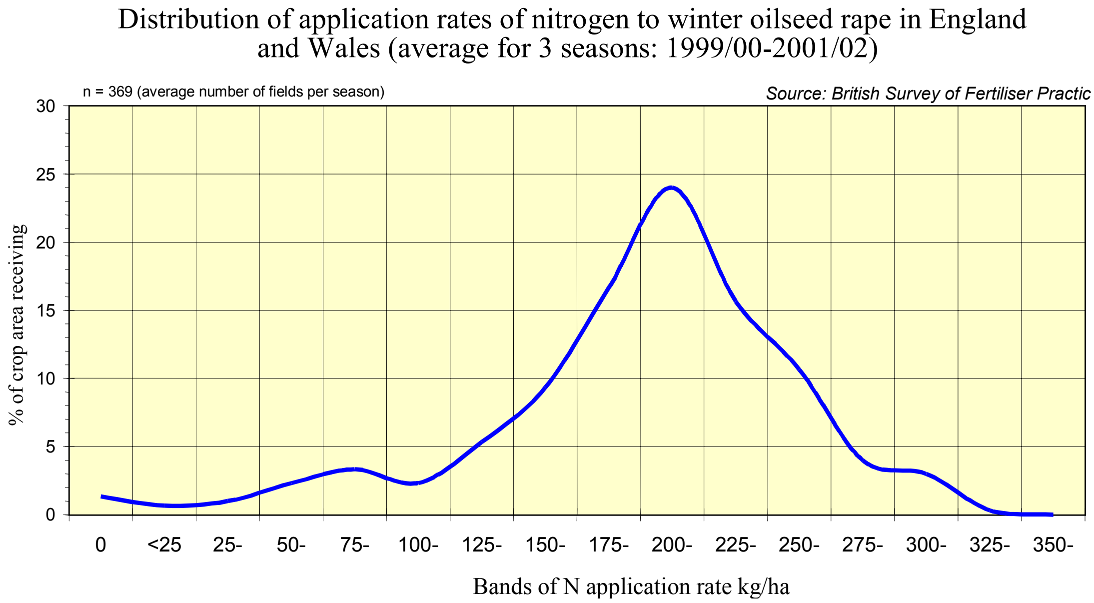
2.3.1.2 Crop nitrogen requirements and fertiliser recommendations

The nutrition and fertiliser requirement of oilseed rape has been extensively reviewed by Chalmers *et al.* (1991). Experimental evidence on the need for seedbed nitrogen is conflicting. Some studies in the 1970s and 1980s indicated an economic response to autumn nitrogen, but statistically significant yield increases were only observed at a small proportion of the sites. These sites tended to be those with the greatest yield potential (Holmes and Ainsley, 1978; Chalmers *et al*., 1991). Yield responses were at most in the order of 0.1- 0.2 t/ha. Many other studies have found little or no yield response. When autumn nitrogen is applied, optimum rates of spring nitrogen fertiliser have been found to be lower suggesting that there is no unique benefit from applying nitrogen in the seed bed and that the total nitrogen supply to the crop is the most important consideration (Chalmers *et al*., 1991). The major period of nitrogen uptake by winter crops is during spring growth. Uptake then slows during flowering so that maximum offtake in above ground biomass coincides with the end of flowering. The total nitrogen content of the crop then declines as leaf tissue is shed. The requirement for spring nitrogen fertiliser depends on the nitrogen status of the soil and the crop demand.

Current fertiliser recommendations for winter crops in England and Wales are 120-250 kg/ha for mineral soils with an Soil Nitrogen Status (SNS) index of between 3 and 0 (MAFF, 2000). Of this, 30 kg/ha is recommended for the seedbed on soils with an SNS index of 0-2. The large majority of crops from 1999 to 2002 received nitrogen within this recommended range (Figure 2.3.2). Recommendations by SAC for

Scotland are comparable ranging from 160-230 kg/ha for mineral soils depending on previous cropping (groups 1-4, Sinclair, 2002). Lower rates are recommended for crops following some vegetable crops and long-term high nitrogen input grassland. However these situations are not common. Some adjustment to the rate is advised to account for variations in soil depth and winter and early spring rainfall.

Figure 2.3.2 Distribution of application rates of nitrogen to winter oilseed rape in England and Wales.



2.3.1.3 Varietal differences in nitrogen requirement

At present fertiliser recommendations take no account of possible differences between varieties in nitrogen demand. Some hybrid types, with their greater biomass production and yield potential might be expected to have a greater requirement for nitrogen than conventional varieties. However, there is little experimental evidence to support this view. A recent investigation of the response to nitrogen fertiliser by a range of conventional open pollinated varieties, restored hybrids, varietal associations and transgenic restored hybrids found no significant differences between the variety types (Anon, 2000). These experiments were conducted in Belgium, Denmark, France, Germany, Sweden and the UK. On the other hand, Baer and Frauen (2003) reported that hybrids might be more responsive to nitrogen in some seasons. Genotypic variation has been found in the response of oilseed rape to *low* nitrogen supply. The greater efficiency of some varieties was associated with a higher uptake efficiency (Horst *et al.*, 2003).

2.3.1.4 Contribution of nitrogen fertiliser application rates to poor yield performance

Although rates of nitrogen fertiliser applied to crops declined between 1980 and the mid 1990s there is little evidence to suggest that this has contributed significantly to the lack of yield improvement found in commercial crops over the last 20 years. The reduction was made in response to revised fertiliser recommendations rather than an unwillingness of farmers to apply recommended rates. Currently most crops receive N within the recommended range. According to Figure 3 in Chalmers *et al*., (1991), a reduction in nitrogen from 280 to 200 kg/ha is at most likely to be associated with a yield response of 0.1 t/ha.

When fertilisers are applied according to recommendations based on estimates of residual soil nitrogen (from previous cropping or soil nitrogen measurements), inevitably a proportion of crops will be under supplied and a proportion over supplied. This arises because of variation in crop growth and uncertainties in predicting crop demand and the availability of soil nitrogen. However in European fertiliser trials (Anon, 2000), the number of sites that were over supplied (i.e. showed no yield response over the range of fertiliser rates applied) exceeded those that were under supplied (where the yield response was not saturated by the highest rate applied). Improvements in the prediction of soil nitrogen availability and crop demand for nitrogen will help improve the accuracy of fertiliser recommendations. However, this is a general requirement for all crops and not specifically oilseed rape. Thus, sub-optimal supplies of nitrogen to some crops, resulting from unusually low soil nitrogen availability or high crop demand, is unlikely to affect oilseed rape any more than it does cereal crops, and yet the failure of commercial yields to improve is a problem associated with oilseed rape and not cereals.

Available records from RL trials are incomplete with regard to nitrogen application, hence a comparison of commercial crop inputs with the RL trial inputs was not possible.

In conclusion, nitrogen applications have declined substantially over the past 15 years by over 80 kg/ha, to a mean of 193 kg/ha. However, using standard response curves, this accounts for almost 0.1 t/ha in terms of yield response. Therefore it would appear that even this comparatively large reduction has not made a significant contribution to the failure of the commercial crop to show a progressive yield increase.

2.3.2 Effect of sulphur application on yield

2.3.2.1 Sulphur demand, supply and losses

Along with nitrate, phosphate and potash, sulphur is one of the major elements required for plant growth and is involved in a number of plant functions. Oilseed rape has a relatively high demand for sulphur, requiring approximately 16 kg S to produce one tonne of seed at 91% dry matter (McGrath *et al*., 1996). This gives a total uptake in excess of 50 kg/ha for an average crop yielding over 3 t/ha, with a consequently greater requirement for higher yields.

Sulphur has been traditionally supplied to crops indirectly, both through application of fertilisers applied primarily for the other nutrient they contained, and through atmospheric deposition of emissions from industrial processes, particularly power stations. Changes in practice since the early 1980s has led to supply of sulphur from these sources being substantially reduced. There has been a move away from using single superphosphate and ammonium sulphate, which supplied 12 and 24% sulphur respectively, to the sulphur free, high analysis fertilisers, urea, single superphosphate, ammonium nitrate and ammoniated phosphates.

Environmental concerns over acid rain led to legislation to reduce emissions of sulphur dioxide, one of its main contributors. This has resulted in emissions in the UK reducing from their peak of almost 3.25 million t/year of sulphur in 1970 to around 0.5 million t/year currently (McGrath *et al*., 2002). The reduction in emissions is associated with a similar scale of reduction in sulphur deposition from the air, with deposition at Woburn Farm, Bedfordshire declining from 70 kg S/ha/year at the peak in 1970 to less than 10 kg S/ha/year in 1996/98. McGrath *et al*. (2002) calculated that total S deposition over northern European areas, with rainfall of 600 – 800 mm per year was around 6 – 12 kg S/ha. Industry has been successful in effecting a rapid control of sulphur emissions and this has led to a much earlier reduction in sulphur deposition than previously anticipated. Increased yields and cropping intensity over recent decades have further depleted sulphur supplies.

Sulphur is relatively easily lost from soils through leaching. A soil which did not receive sulphur fertiliser at Woburn in England was shown to leach 35kg/ha (Riley *et al*., 2002) over a 3 year period. Application of sulphur resulted in considerably higher losses, with the same soil receiving 50 kg/ha sulphur as ammonium sulphate fertiliser leaching 83 kg S/ha over the 3 years. Accounting for atmospheric deposition, fertiliser application, plant uptake and leaching, the balance over the 3 years was –33 and –35 kg S/ha for the untreated and ammonium sulphur treatments respectively. A study of the Broadbank experiments at Rothamsted which had received sulphur fertilisers for the last 150 years, showed that even greater leaching losses of 60 kg S/ha were noted in one year, almost 10 kg S/ha more than that applied as fertiliser (Knights *et al*., 2000). Work tracing anthropogenic sulphur has shown that sulphur deposited from the atmosphere in the past is rapidly being removed by crop uptake and through leaching.

2.3.2.2 Sulphur deficiency and yield responses

Observed sulphur deficiency in crops has been increasing in frequency since the early 1980s. Oilseed rape, with its very high demand for sulphur, was one of the first crops to show symptoms, particularly in combination with light sandy soils, which have limited ability to retain sulphur, and remoteness from industrial areas, giving low atmospheric deposition. Sulphur deficiency has been seen on lighter soils in

Scotland, where atmospheric deposition has always been low, since the area of the crop cultivated expanded in the early 1980s (Brokenshire *et al*., 1984). In England, crop responses to sulphur fertiliser have been noted since the 1990s (McGrath *et al*., 2002).

A review of crop responses to sulphur fertilisation found that 29 out of 78 field trials (37%) on winter and spring oilseed rape carried out between 1987 and 2002 across the UK, showed a significant yield response to sulphur application (Zhao *et al*., 2002). Work in Germany, Denmark and France has also shown yield response to sulphur and has indicated that sulphur responsiveness is growing. Responsiveness to sulphur application varies, with many trial series showing a variation in yield response across sites. A series of 16 experiments conducted in 91/92 and 92/93 seasons on a range of soil types across the UK found large significant responses in yield, from 15 to 74% (0.36 to 0.84 t/ha) at 5 sites on sandy soils or soils over chalk (Withers *et al*.,1995). A further 4 sites exhibited transient sulphur deficiency but no resulting yield response. Yield responsiveness can vary greatly within a short distance, with overall yield on a high sulphur site situated only 100m away from a low sulphur site being 4.54 t/ha compared to 2.39 t/ha (Booth *et al*., 1991). Application of sulphur in this trial resulted in responses of between 59% and 288% depending on the variety, with low glucosinolate varieties being more responsive than the old high glucosinolate types. An interaction with nitrogen applied was also observed with yield from treatments receiving no sulphur being further depleted by higher N application. The importance of a balanced nitrogen and sulphur nutrition has also been noted in other field work (Zhao *et al*., 1993; McGrath and Zhao, 1996).

Modelling work to anticipate likely future response to sulphur fertiliser was carried out by McGrath and Zhao in 1995. At this time it was predicted that 50% of the land area of Britain would have a high risk of sulphur deficiency and 20% had a medium risk. Later work by McGrath *et al*. (2002) notes that few of the crop trials considered were undertaken in recent years when the sulphur input from atmospheric deposition had declined so markedly. With the quicker than expected achievement of reduction of emission up to 2000, areas at risk may require further revision. These factors have meant that it has been difficult to effectively transmit advisory information to growers on sulphur application (Walker and Dawson, 2002). Progressively declining sulphur deposition has led to results becoming outdated and areas responsive to sulphur fertiliser continuously expanding. The identification and rectification of sulphur deficiency by growers and advisors was also cited by Walker and Dawson (2002) as a major challenge.

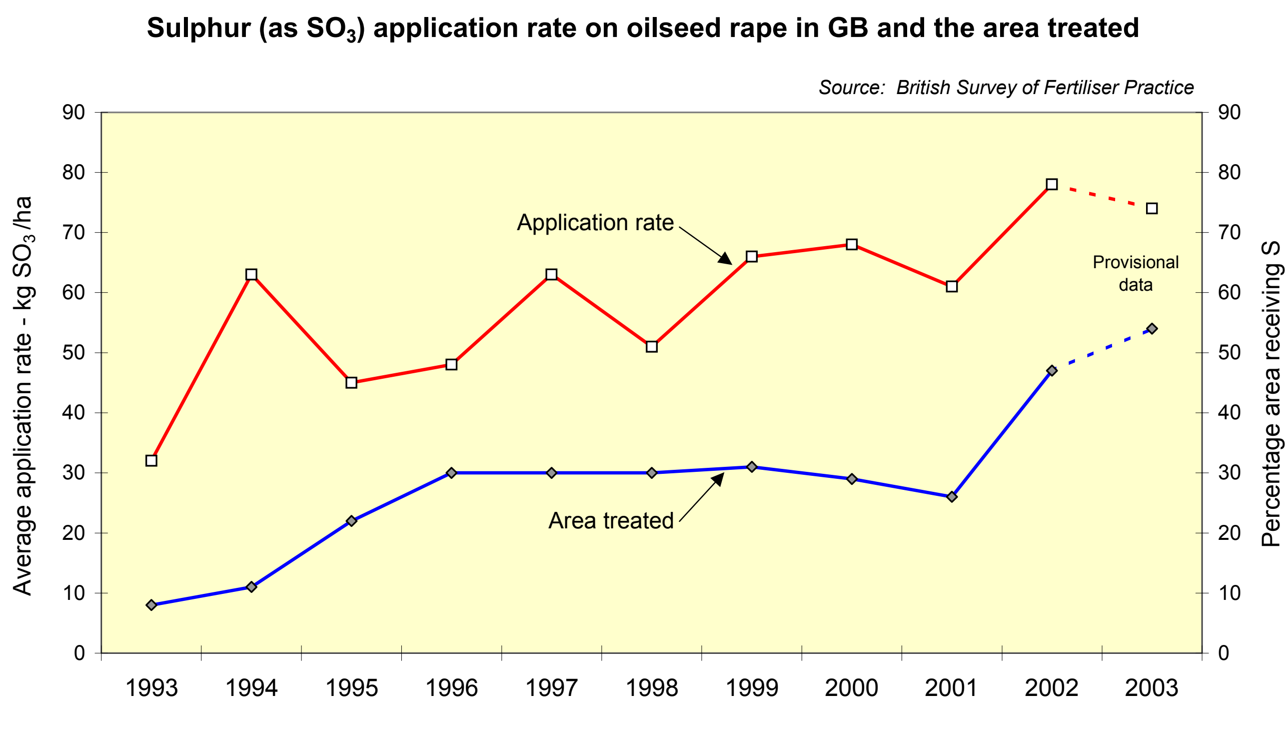
2.3.2.3 Sulphur fertiliser application in the UK

Data from the British Fertiliser Survey (Figure 2.3.3) indicates that the amount of sulphur applied to all crops has been slowly rising since the early 1990s. Where sulphur is applied, oilseed rape now receives around 25 kg S/ha (around 70 kg SO_3). It is perhaps of even greater interest to note the percentage of oilseed rape grown commercially receiving sulphur. In the early 1990s this was extremely low at less than 10% (in 1993). The proportion of oilseed rape receiving sulphur increased until 1996, when sulphur was applied to

30% of oilseed rape land and remained relatively static until 2002, coinciding with the notable reduction in provision of sulphur through atmospheric deposition. In 2002 and 2003, the proportion of oilseed rape treated with sulphur increased to around 45%, but even this leaves the majority of land receiving no sulphur fertiliser and is at odds with the estimate of 70% of land being at either high or medium risk of sulphur deficiency.

It may be expected that more particular attention to optimum agronomy is given to Recommended List trials compared to the commercial crop. This would tend to include a greater incidence of sulphur application than on the commercial crop. Examination of data relating to RL inputs shows that there is very little information available on level of sulphur application, hence direct comparison of inputs with the commercial crop cannot be made. Because trials are regularly inspected by experienced agronomists aware of the risk of sulphur deficiency, and as the protocol specifically requires an application of 30 kg S/ha to trials in the spring, the yield limiting effect of sulphur deficiency in trials is considerably less likely compared to commercial crops.

Figure 2.3.3 Application rate of sulphur to oilseed rape (as SO_3/ha) and area treated (as percentage of oilseed rape area) in Great Britain



2.4 Other factors which are considered to have a smaller effect on yield progression

Several other factors were considered for their potential to affect yields of the commercially grown oilseed rape crop. These are discussed below.

2.4.1 The effect of weeds and application of herbicides on yield

Broad-leaved weeds are generally not competitive with perhaps a few exceptions such as cleaver and chickweed in late or delayed crops. Volunteer cereals are competitive, but are readily controlled. It is considered (K Davies, personal communication, 2004) that levels of weed control has not decreased significantly over the period of oilseed rape cultivation in the UK and therefore that weed occurrence and control is unlikely to be an important factor in reducing yield of the commercial oilseed rape crop. There may be more seasonal variation rather than any long term trend. Herbicide resistance with black-grass may be overcome in the oilseed rape crop by use of alternative herbicides.

2.4.2 Other diseases

Clubroot is known to affect parts of Scotland, in particular the North-East where it is thought to be associated with the mixed farming practices of the area with a history of swede/turnip cultivation. In England and Wales, it is recorded in the Defra disease survey as being present or absent at the time of pod ripening. Levels recorded have been very low for the Defra funded survey. Clubroot was not recorded in most years and only recorded at trace levels in other years. There was no regional pattern in incidence. National incidence for those years when clubroot was recorded was as follows: 1987 – 0.002% plants affected, 1990 – 0.01% plants affected, 1991 – 0.013% plants affected, 1993 – 0.01% plants affected, 2003 – 0.004% plants affected. On this basis, clubroot was discounted as a major factor involved in reducing the national oilseed rape crop yield.

Root diseases of oilseed rape were investigated in a preliminary study by Evans *et al*. (2003), due to concerns about variability of senescence of oilseed rape stems in the 2000/01 season from crops in the southern part of the country which had a history of oilseed rape in the rotation. Roots of affected plants were blackened and stunted. It was determined that this was due to infection of the roots by the stem canker pathogen at and around harvest as the host plant underwent maturation and senescence. However, it was concluded that this was unlikely to responsible for any yield loss, but may provide a significant source of inoculum for infection of a following crop. There was no further evidence to suggest that root disease have significant effect on yield of the oilseed rape crop.

2.4.3 Pests/pesticides

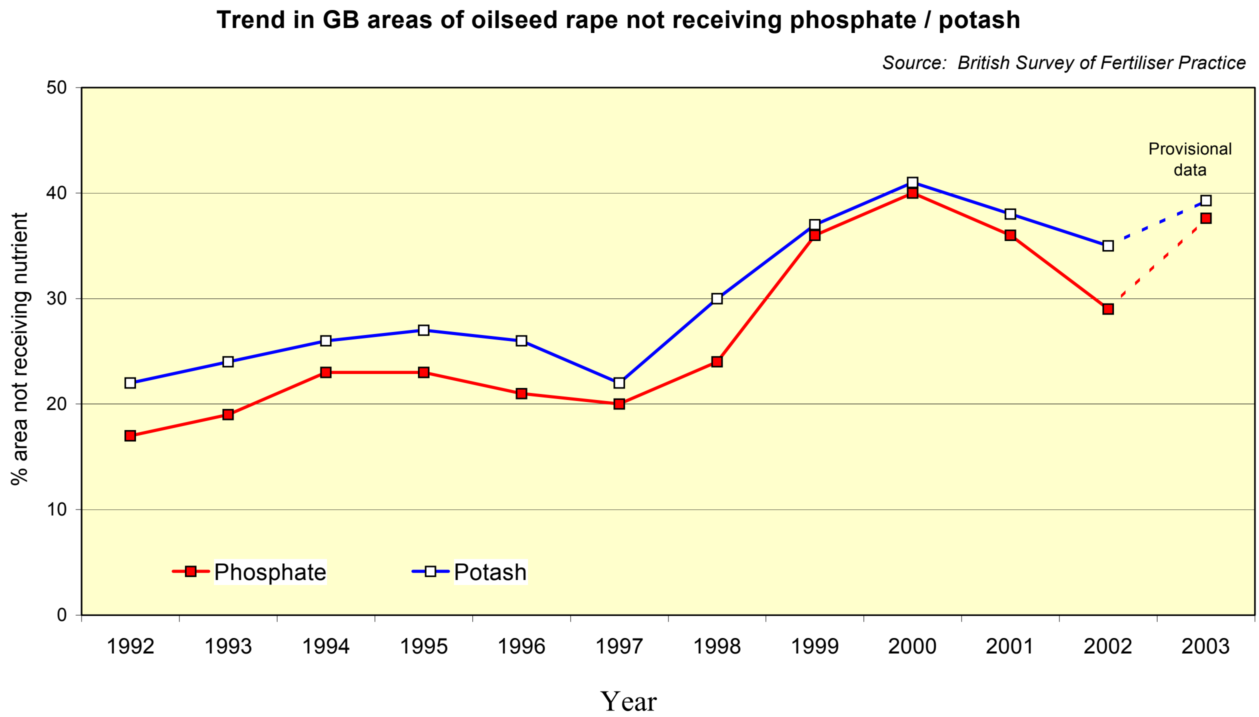
Data from the Defra survey indicates that approximately 7% of sites surveyed recorded ‘much’ damage from slugs from 1997. Very low number of sites (<1%) showed significant scarring from cabbage stem flea beetle, and only very low proportions of sites (again <1%) sampled had numbers of cabbage seed weevil and pollen beetle over the threshold for control. There were no apparent significant differences between years.

The overall message from this data is that pests are unlikely to be a major factor in the lack of yield improvement of the commercial crop.

2.4.4 The application of phosphate and potash

In most UK soils, reserves of readily-available phosphorus and potassium levels have been built up to satisfactory levels due to past fertiliser and organic manuring practice. In an effort to reduce production costs, farmers have reduced applications of these nutrients in recent years (Figure 2.4.1). It is considered that omission of phosphorus and potassium fertiliser for a few years will not impact on yields, unless the soil status is already low (Johnston *et al*., 2002). The continuation of depletion of soil reserves may lead to yield losses and attention is drawn to the importance of balanced crop nutrition to ensure that yields of the commercial oilseed rape crop are not impaired by this factor.

Figure 2.4.1 Percentage area not given applications of phosphorous and potassium



2.4.5 Establishment techniques

The use of minimum tillage establishment techniques may give rise to higher risks for achieving successful establishment of crops in particular soil conditions influenced by soil type and season. There is no evidence to suggest that this has influenced the national commercial yield. The effect of home saving seed was investigated by Sutherland *et al*., (2004). No depression in yield was attributed to seed that had been home saved in these trials. Details of establishment techniques utilised and whether home saved seed has been used are not available from the Defra disease survey, and no further data are available to indicate the extent of these practices.

Section 3: Conclusions

1. In general, yields in trials are nearly always greater than from commercially grown crops. For oilseed rape, a number of factors may contribute to this, including the yield potential of the selected trial site (soil type, site uniformity aspect etc.) and more careful management of the trial compared to the field crop e.g. more timely disease control. Statistical analysis confirms that yield of oilseed rape from RL trials has increased by approximately 0.033 t/ha/year since 1987, whereas there has not been an increase in yield of the commercial crop over the same time period. This has also been found to occur when the RL trial yields are adjusted to represent a similar varietal composition to the national commercial crop in any given year. The difference between trial and commercial yields has tended to increase over time. The major period over which this difference increased was the early 1990s. Thereafter, the difference returned to pre-1990 values, but is now increasing again.

2. An increase in disease levels, especially light leaf spot can quantitatively account for the increase in yield differential between RL trials and the commercial crop in the early 1990s. This was associated with the use of susceptible varieties and failure to treat some crops. An improvement in disease control coincided with a period of decline of the differential in yield.

3. Another important factor in preventing the progression of yield in the oilseed rape crop is that of sulphur. It is not possible to quantify the contribution of sulphur deficiency to the yield differential, but it is considered that this factor is likely to be implicated. Sulphur deposition from the atmosphere has declined more rapidly than anticipated in the 1980s and 1990s with the result that at least 50% of crop area is now at high risk of sulphur deficiency and 20% is at moderate risk. Non RL trial results show that yield responses are variable, but are becoming more frequent and were shown to be up to 288% at responsive sites across the UK. Only 25% of the oilseed rape area in the UK is treated with sulphur.

4. Variations in proportion of spring to winter sown crops may have contributed a small amount (possibly 0.1 t/ha) to the variations in the yield differential, especially in 1994 and 1995 when the percentage of spring crop rose to around 25%.

5. Lower inputs of nitrogen, as a consequence of reduced commodity prices, have a much lesser effect on yield of the commercial crop. Nitrogen applications have declined from 280 kg/ha in 1984 to 193 kg/ha in 1996 - 2000 (British Survey of Fertiliser Practice). However, this relates to only 0.1 t/ha on the response curve, hence the lower input of nitrogen cannot be regarded as a major factor in constraining development of yield of the commercial crop.

6. A number of factors can be largely discounted as influencing the lack of progress of oilseed rape yields. Examination of the influence of regional bias to the national yield of oilseed rape showed that this was

not a major factor in terms of the lack of yield progression. Introduction of the practice of cultivating oilseed rape on set aside has not resulted in a significant effect on commercial yields.

7. A range of other factors such as establishment techniques and over-early sowing may also be involved, but their contribution to the overall failure of the commercial crop yields to improve cannot be quantified. These factors may be important at a local level.

8. Assuming improvements in yield potential through breeding continue, it is necessary to ensure that appropriate agronomy maximises the chances of realising variety potential.

9. The major factors involved in lack of yield progress with the UK commercial crop can be ranked as disease, sulphur, reduced nitrogen levels and, in certain years, increased spring rape area.

10. Considerable research work has been carried out on disease and sulphur topics over the years and recommendations from this work offer the farmer opportunities for implementing disease control strategies and avoidance of sulphur deficiency. Indeed, disease-forecasting systems are now in the advanced stages of development that will help farmers to assess the appropriate level of disease control for the season. However there are difficulties in achieving uptake of advice and an example of this may be shown with sulphur, where the proportion of crops treated and levels of input applied are far less than that estimated to be required. In order to achieve closer to the practical potential oilseed rape yield, as demonstrated by RL trials, and to develop an upward trend in national commercial yield, it is necessary to ensure that the messages from this and associated research projects are delivered to farmers and acted upon.

References:

Anon. (2000) FACTT final report. EU project to promote familiarization with and acceptance of crops incorporating transgenic technology in modern agriculture. CT-95-0364.

Anon. (2001) The British Survey of Fertiliser Practice, 2001. Fertiliser Use on Farm Crops for Crop Year 2000, Defra 2001, 108pp.

Baer, A.& Frauen, M. (2003) *Yield response of winter oilseed rape hybrids to sowing date, sowing density, nitrogen supply and triazole input*. Proceedings of 11th International Rapessed Congress III, pp 887-892.

Booth, E.J., Walker, K.C. & Schnug, E. (1991) The effect of site, foliar sulphur and nitrogen application on glucosinolate content and yield of oilseed rape (*Brassica napus* L.). *Proceedings of the Eighth International Rapeseed Congress*, Saskatoon, Canada, pp 567-572.

Brokenshire, T., Channon, A.G. & Waler, S. (1984) Recognising oilseed rape diseases. Publication **135**, *The Scottish Agricultural Colleges*, Edinburgh.

Bunting, E.S. (1986) Oilseed rape in perspective. In: Oilseed rape (eds. DH Scarisbrick and RW Daniels), Collins, London.

Chalmers, A.G., Darby, R.J., Evans, E.J., Sinclair, A.H. & Withers, P.J.A.. (1991) *Crop Nutrition and Fertilizer Requirements for the Double Low Oilseed Rape Crop*. HGCA Review Article, p154. Home Grown Cereals Authority, London.

Draper, & Smith, (1981) Applied regression analysis. Wiley, New York.

Evans, N., Steed, J., Fitt, B., Norman, K., Bryson, R., Alford, J. & Cavell, P. (2003) Preliminary evaluation of root disease of winter oilseed rape in the UK. Project Report No. OS62, HGCA, London.

Fitt, B.D.L., Gladders, P., Turner, J.A., Sutherland, K.G., Welham, S.J. & Davies, J.M.Ll., (1997) Prospects for developing a forecasting scheme to optimise use of fungicides for disease control on winter oilseed rape in the UK**.** *Aspects Applied Biology* **48**, 135-142.

Fray, M.J., Evans, E.J., Lydiate, D.J. & Arthur, A.E. (1996) Physiological assessment of apetalous flowers and erectophile pods in oilseed rape (*Brassica napus*). *Journal of Agricultural Science, Cambridge,* **127**: 193-200.

GenStat (2002) *GenStat for Windows. Release 6.2.* Oxford: VSN International Ltd.

Gladders, P. (1988) The contribution and value of pesticides to disease control in combinable break crops. In: *Control of Plant Diseases: Costs and Benefits*, pp 29-50. Eds. B.C. Clifford and E. Lester. Oxford: Blackwell Scientific Publications.

Holmes, M.R.J., Ainsley, A.M. (1978) Nitrogen top-dressing requirements of winter oilseed rape. *Journal of the Science of Food and Agriculture* **30**, 119-128.

Horst,W.J., Behrens, T., Heuberger, H., Kamh, M., Reidenbach, G. & Wiesler, F. (2003) Genotypic differences in nitrogen use-efficiency in crop plants. In Lynch JM, Schepers JS and Unvers I (eds.) *Innovative soil-plant systems for sustainable agricultural production*. Pp 75-92. OECD.

Jenkins, P.D. & Leitch, M.H. (1986) Effects of sowing date on the growth and yield of winter oilseed rape (*Brassica napus*). *Journal of Agricultural Science, Cambridge* 105: 405-420.

Johnston, A.E., Goulding, K.W.T., Poulton, P.R. & Chalmers, A.G. (2002) Reducing fertiliser inputs:endangering arable soil fertility? The International Fertiliser Society, **487**, York.

Knights, J.S., Zhao, F.J., Spiro, B. & McGrath, S.P. (2000) Long-term effects of land use and fertilizer treatments on sulphur-cycling. *Journal of Environmental Quality*, **29**, 1867-1874.

MAFF (2000) *Fertilizer Recommendations for Agricultural and Horticultural Crops* (RB209). p 88. The Stationary Office, London.

McGrath, S.P. & Zhao, F. (1996) Sulphur uptake, yield responses and the interactions between nitrogen and sulphur in winter oilseed rape (*Brassica napus*). *Journal of Agricultural Science*, Cambridge, **126**, 53-62.

McGrath, S.P., Zhao, F. & Blake-Kalff, M.M.A. (2002) History and outlook for sulphur fertilisers in Europe. *The Internaional Fertiliser Society*, **497**, York.

McGrath, S.P., Zhao, F.J. & Withers, P.J.A. (1996) Development of sulphur deficiency in crops and its treatment. *The Fertiliser Society*, **379**, York.

Mendham, N.J., Shipway, P.A. & Scott, R.K. (1981) The effects of delayed sowing and weather on growth, development and yield of winter oilseed rape (*Brassica napus*). *Journal of Agricultural Science, Cambridge* 96: 389-416.

Riley, N.G., Zhao, F.J. & McGrath, S.P. (2002) Leaching losses of sulphur from different forms of sulphur fertilizers: a field lysimeter study. *Soil Use and Management*, **18**, 120-126.

Sansford, C.E., Fitt, B.D.L., Gladders, P., Lockley, K.D. & Sutherland, K.G. (1996) Oilseed rape: development, forecasting and yield loss relationships. *HGCA Project Report No. OS17*, 185pp. London:HGCA.

Sinclair, A.H. (2002) *Nitrogen Recommendations for Cereals, Oilseed rape and Potatoes*. SAC Technical Note T516. Scottish Agricultural College, Edinburgh.

Spink, J.H., Lunn, G.D., Clare, R.W. & Foulkes, M.J. (2002) Sowing date and seed rate in wheat and oilseed rape. In: *Agronomic intelligence: the basis for profitable production*. Proceedings HGCA R & D Conference, Coventry 2002 pp 3.1-3.13.

Stokes, D.T., Scott, R.K., Clare, R.W., Spink, J.H., Bullard, M.J. & Sylvester-Bradley, R. (1998) Establishment and canopy management in oilseed rape. In: Management through understanding into practice. Proceedings HGCA R & D Conference, Cambridge 1998 pp 6.1-6.12.

Su, H., Fitt, B.D.L., Welham, S.J., Sansford, C.E. & Sutherland, K.G. (1998) Effects of light leaf spot (*Pyrenopeziza brassicae*) on yield of winter oilseed rape (*Brassica napus*)**.** *Annals Applied Biology* **132**, 371-386.

Sylvester-Bradley, R, Lunn, G., Foulkes, J., Shearman, V., Spink, J. & Ingram, J. (2002) Management strategies for high yields of cereals and oilseed rape. In: *Agronomic intelligence: the basis for profitable production*. Proceedings HGCA R & D Conference, Coventry 2002 pp 8.1-8.17.

Tommey, A.M. & Evans, E.J. (1991) Temperature and daylength control of flower initiation in winter oilseed rape (*Brassica napus*). *Annals of Applied Biology* 118: 201-208.

Walker, K.C. & Dawson, C.J. (2002) Sulphur fertiliser recommendations in Europe. *The International Fertiliser Society*, **506**, York.

Withers, P.J.A., Evans, E.J., Bilsborrow, P.E., Milford, G.F.J., McGrath, S.P., Zhao F. & Walker K.C. (1995) Development and prediction of sulphur deficiency in winter oilseed rape. Project Report No. OS11, HGCA, London.

Zhao, F., Evans, E.J., Bilsborrow, P.E. & Syers, J.K. (1993) Influence of sulphur and nitrogen on seed yield and quality of low glucosinolate oilseed rape (*Brassica napus* L). *Journal of the Science of Food and Agriculture*, **63**, 29-37.

Zhao, F.J., McGrath, S.P., Blake-Kalff, M.M.A., Link, A. & Tucker, M. (2002) Crop responses to sulphur in Europe. *The International Fertiliser Society*, **504**, York,

Appendix 1 Region classifications

This corresponds to the Defra English regions, as used from 1995 onwards, plus Wales and Scotland. The table shows the English counties only.

County	Region
Northumberland	NE
Tyne and Wear	NE
Durham	NE
Cleveland	NE
Cumbria	NW
Lancashire	NW
Cheshire	NW
Greater Manchester	NW
Merseyside	NW
North Yorkshire	YORKS
East Yorkshire	YORKS
West Yorkshire	YORKS
South Yorkshire	YORKS
Derbyshire	EM
Nottinghamshire	EM
Lincolnshire	EM
Leicestershire	EM
Northamptonshire	EM
Staffordshire	WM
Shropshire	WM
Hereford & Worcester	WM
West Midlands	WM
Warwickshire	WM
Norfolk	E
Suffolk	E
Cambridgeshire	E
Bedfordshire	E
Hertfordshire	E
Essex	E
Greater London	SE
Surrey	SE
Kent	SE
East Sussex	SE
West Sussex	SE
Hampshire	SE
Isle of Wight	SE
Oxfordshire	SE
Buckinghamshire	SE
Berkshire	SE
Gloucestershire	SW
N Somerset	SW
Wiltshire	SW
Somerset	SW
Dorset	SW
Devon	SW
Cornwall & Isles of Scilly	SW

Appendix 2 Disease and yield loss relationships in winter oilseed rape

In 1991, Hardwick *et al.* identified the main diseases of oilseed rape as light leaf spot, Phoma stem canker and Alternaria leaf and pod spot, with several other diseases considered less important or of no importance at all (Table l). Light leaf spot and Phoma stem canker are still considered the most important diseases in the UK, but Sclerotinia is also perceived as important in terms of fungicide control. Whether this is justified in terms of actual disease risk is not clear as the proportion of unsprayed crops has reduced markedly. The Defra-funded National Survey shows that Sclerotinia stem rot has not increased since the epidemic in 1991 (Hardwick *et al*., 1991), whereas Alternaria pod spot has been particularly prevalent in more recent years. Table 2 compares disease incidence recorded in the National Survey in 1991 with levels in more recent years.

Table 1 Importance of oilseed rape diseases in 1991

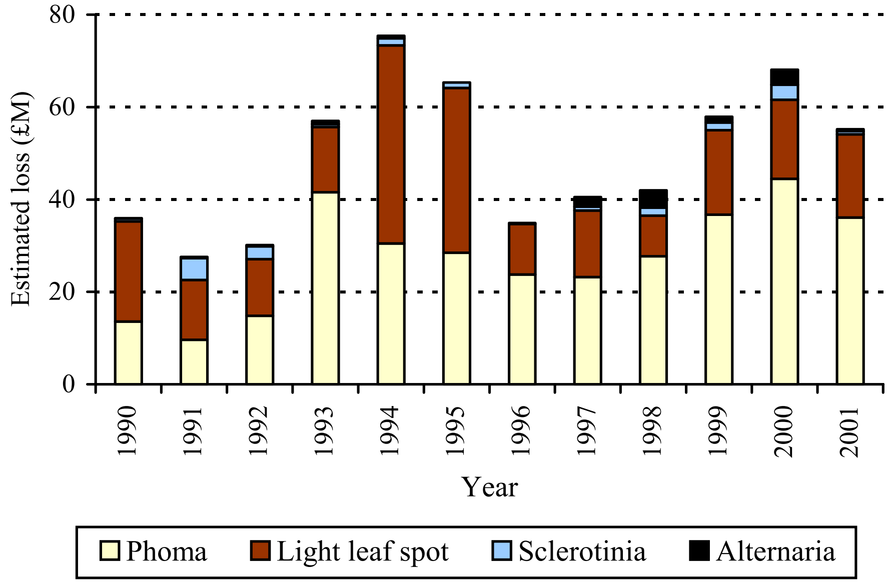
Major importance	**Some importance**	**No importance**
Light leaf spot Phoma Alternaria	Sclerotinia Botrytis Beet Western Yellows Virus (BWYV)	Clubroot Damping-off Rhizoctonia Phytopthora root rot Powdery mildew Downy mildew White leaf spot Ringspot White blister

Table 2 Disease incidence at pod ripening in 1991 compared to 2000-2002 (% plants affected)

	Alternaria pod spot	Light leaf spot (stems)	Phoma canker	Sclerotinia stem rot	Downy mildew (pods)	Powdery Mildew (pods)
1991	13.0	14.8	11.1	5.4	3.1	1.1
2000	31.5	21.8	56.8	4.1	16.4	6.9
2001	6.1	27.1	54.2	1.1	3.4	1.7
2002	40.9	30.2	52.9	2.3	2.9	18.1

Figure 1 shows losses due to diseases after the application of fungicide treatments. These figures have been estimated from Defra-funded survey data using the models described by Sansford (Fitt *et al*., 1997).

Figure 1 Estimated yield losses (£ Million) due to diseases in fungicide treated crops.



In the early 1980s, 5% of crops in Scotland received a single fungicide spray in the summer for Alternaria control with the remainder unsprayed (Jeffrey *et al*., 1983). By 1988 these figures had reversed, with 92% of crops receiving a fungicide spray, 20% in the autumn, 46% at stem extension and 21% in May (Snowden *et al*., 1991). In England & Wales during 1986-88, 42% of crops never received a fungicide, with only 3% of crops sprayed in the autumn and 55% of crops sprayed at stem extension/flowering in the spring (Hardwick *et al*., 1989). Between 1987 and 2000, the number of crops sprayed in the autumn increased significantly from 3.2% to 80% while the proportion sprayed at stem extension increased to a lesser extent from 36.6% to 50% (Hardwick, 1987 & Turner *et al*., 2000a). In 1987 flowering sprays were applied to 16.1% of crops. Since 1992, the proportion of crops receiving flowering sprays, principally targeted at Sclerotinia, has increased markedly in response to the stem rot epidemic of 1991. In 2000, 32.2% of crops received a spray at this timing. Conversely, the number of sprays applied post-flowering, principally for control of Alternaria pod spot, dropped. In 1987, 40.9% of crops received a post-flowering spray, compared to only 2.2% in 2000.

<u>Effect of light leaf spot on yield</u>

Light leaf spot is a polycyclic disease, with repeat infections occurring throughout the year (Anon, 2004a). Initial infection occurs in the autumn *via* wind-borne ascospores or rain splashed conidiospores produced on the previous year's stubble and trash. Subsequently, rain splashed conidiospores spread the disease within fields and onto upper leaves, bracts, flowers and pods of infected plants. In many cases infection occurs as soon as the crop emerges, but symptoms of leaf spotting do not appear until December-February, reaching a maximum at the green bud stage of growth (GS 3.3) in the spring (Sutherland *et al*., 1995). Autumn infections of light leaf spot are the most damaging, causing leaf loss, crop stunting and loss of plants overwinter (Baierl *et al*., 2002). Growers in Scotland routinely apply fungicides for control of light leaf spot in the autumn and again in the spring at stem extension (Sutherland *et al*., 1995). However, due to lower disease pressure in the late 1980s and early 1990s growers in England & Wales either did not control light leaf spot or applied fungicides in the spring (Hardwick *et al*., 1991). Increases in disease levels and further research showed that many crops in England & Wales also required autumn treatment for light leaf spot (Rawlinson *et al*., 1984; Fitt *et al*., 1997). This was demonstrated by Turner *et al*. (2000b) using survey data from 1995 to 1999 (Table 3). With the exception of 1995, when disease pressure was very high, use of autumn sprays was shown to be the most effective strategy for light leaf spot control.

Table 3 Incidence of light leaf spot stem disease in relation to fungicide timing, 1995 - 1999.

		% plants affected with stem symptoms				
Disease	Spray timing	1995	1996	1997	1998	1999
Light leaf spot	Autumn	70.0	5.4	7.1	0.9	15.3
	Spring	52.4	14.0	35.4	24.4	32.9
	Autumn + Spring	50.5	12.9	11.7	8.0	18.0

In England, Rawlinson *et al*. (1984) found yield responses to autumn fungicides in the range of 0.4 – 0.57 t/ha and in Scotland Wale *et al*. (1990) found responses to 2 and 3 fungicide sprays in excess of 1 t/ha. Wale *et al*. (1990) also found there was no clear pattern between yield response and severity of light leaf spot; cultivars with lower disease levels often gave higher yield responses to fungicide than cultivars with much higher disease infection. Sutherland *et al*. (1995) found that severe disease epidemics did not necessarily result in higher yield losses. Yield responses in seasons with low light leaf spot epidemics were often far greater than in seasons with severe epidemics.

Sansford *et al*. (1996) showed a strong linear relationship between light leaf spot incidence on stems (% plants affected) and yield, with an average yield loss of 0.019 t/ha for every 1% stems affected with light leaf spot at the end of the season. This relationship is useful retrospectively but is of little use for controlling light leaf spot during the growing season. However, the amount of disease present on the stems is an indication of the amount of disease present on leaves earlier in the season. Sansford *et al*. (1996) also showed that yield losses due to light leaf spot only occurred once >13% of the leaf area was affected by the disease. In 1994 and 1995, when the major light leaf spot epidemic occurred, the Defra national survey recorded this level of infection in 6.7% of crops in the spring. Sutherland *et al*. (1995) found a negative linear relationship between the area under disease progress curve (AUDPC) for light leaf spot and yield. For every 1% reduction in AUDPC of light leaf spot there was an associated yield increase of 0.00044 t/ha. In a severe light leaf spot epidemic AUDPC could be as high as 2000, eradication of which could result in a yield increase of 1.06 t/ha. Su *et al*. (1998), however, showed that AUDPC could over-estimate yield losses particularly if disease did not subsequently develop on stems and pods and also required disease assessments to be carried out throughout the season which was not practical for growers in the field. Su *et al.* developed a simpler model which showed a good prediction of yield loss from light leaf spot could be determined from disease levels on leaves at stem extension (GS 3.3). For every 1% incidence (% plants affected) of light leaf spot on leaves at GS 3.3 there was an associated 0.014 t/ha yield loss. Prediction of yield losses at this time allows growers to take action and apply appropriate spring fungicides. Using the above equations from Sansford *et al*. (1996), Fitt *et al*. (1997) estimated yield losses from light leaf spot in the UK of 88 – 325 kt/annum, or £13-50 Million (Figure 1) (at a seed price of £150/t).

A forecasting system has been developed to predict severe light leaf spot epidemics (Welham *et al*., 2004). The forecast consists of two predicition dates for a crop in a particular region of the UK; an autumn prediction and a spring prediction. The autumn prediction is based on the amount of disease present on pods in oilseed rape at the end of the previous season and autumn rainfall. This predicts the risk of a severe epidemic of light leaf spot occurring in a crop at stem extension and thus the need for an autumn fungicide spray to prevent this epidemic. The spring prediction is based on disease incidence at GS 3.3 and March rainfall and predicts severe light leaf spot on pods at the end of the season and hence the need for a spring fungicide spray. The aim of the forecast is to identify those crops at high risk from light leaf spot and which require fungicide sprays but also, as importantly, to identify those crops at low risk from light leaf spot and which do not require fungicide sprays.

The light leaf spot forecast is available to growers as an interactive web page at http://www3.res.bbsrc.uk/leafspot/forecast. The forecast has been incorporated into a decision support system currently being developed for oilseed rape as part of the Defra/HGCA LINK funded PASSWORD project (HGCA Project No. 2155; Sutherland *et al*., 2002; Gladders *et al.*, 2004).

Effect of Phoma leaf spot and stem canker on yield

Phoma leaf spot/stem canker is a monocyclic disease, producing one cycle of disease each season (Hardwick *et al*., 1991) although spores are released over a period of several months (Gladders & Musa, 1980). Initial infection is *via* ascospores produced on the previous years' stubble (Gladders & Musa, 1980). Ascospores are released in the autumn in response to warm, humid weather (West *et al*., 1999). The first symptoms are leaf spots which are produced on leaves in the autumn, 130 – 160 degree days after infection (Biddulph *et al*., 1999). The fungus grows through the leaf and down the petiole into the stem at a rate of 5 mm/day at 18-20^{o}C (Hammond and Lewis, 1986). In cooler conditions the growth rate is much slower, approximately 1.4 mm/day at 3^{o}C (Hammond and Lewis, 1986) and is the likely reason why epidemics are less severe or absent in the north of England and in Scotland (West *et al*., 1999). If the autumn is dry and cool, leaf spotting development is delayed and canker development is reduced (Gladders & Musa, 1980). Cankers appear on stems approximately 77 – 175 days after infection and 1130 – 1230 degree days after first appearance of leaf spots, usually from March – July depending on the season (Hammond and Lewis, 1986; Gladders *et al*., 2001).

Gladders & Musa (1980) showed that leaf spotting diminished with distance from infected stubble, so one of the main ways of reducing Phoma leaf spot and stem canker is to plough in the stubble, thereby reducing inoculum.

In south-east England crops can have in excess of 75% of plants with moderate and severe cankers causing up to 1 t/ha yield loss (Gladders *et al*., 1999). Early work on fungicidal control of stem canker gave variable results (Rawlinson *et al*., 1984). In many cases fungicides were applied at stem extension but proved ineffective. It was subsequently shown that cankers developed from a systemic infection of plants initiated from leaf spots (Hammond and Lewis, 1986). Fungicides were unable to attack this deep seated infection. Fungicides for control of Phoma stem canker must be applied in the autumn during the leaf spot phase of the disease, to delay and reduce the onset of spotting (Gladders *et al*., 1999). Fungicides need to be applied at the beginning of leaf spot production and delays in this could be the reason for poor control on farm (Gladders *et al*., 1998). Growers, therefore, cannot rely on applying a fungicide at a set time in the autumn, as with light leaf spot control but must time the fungicide application to that of ascospore release. This timing is difficult for growers to determine, and as a result, a system was developed where growers are warned when a threshold of 10% leaf spot incidence occurs in their area and fungicides are applied at this time (West *et al*., 1999).

ADAS trials in the late 1980's showed that the variety Cobra suffered significant yield losses where leaf spotting in the autumn exceeded 20% plants affected (Hardwick *et al*., 1991). Sansford *et al.* (1996) showed stem canker was controlled well with two fungicide sprays in the autumn, with maximum yield responses of 2 t/ha. Gladders *et al*. (1999) showed yield responses approaching 0.8 t/ha from a four spray programme beween November and March.

Sansford *et al*. (1996) showed there was no direct relationship between the incidence of leaf spotting in the autumn and canker development at the end of the season. Conversely, Sun *et al.* (2000) showed that for every 1% increase in Phoma leaf spot in the autumn before GS 1.7 there was an increase in stem canker of 0.9% at harvest. Gladders *et al*. (2001) also showed a strong correlation between the incidence of Phoma leaf spot in the autumn and the incidence of stem canker at harvest. Sansford *et al*. (1996), however, showed there was a strong relationship between canker incidence and severity at harvest and yield loss. For every 1% increase in canker incidence at pod ripening there was an associated yield loss of 0.01 t/ha. Zhou *et al.* (1999) found a similar relationship between stem canker levels at seed ripening (GS 6.3-6.4) and yield loss, for every 1% increase in canker incidence at harvest there was an average yield loss of 1.63%. Zhou *et al.* further showed that cankers present earlier in the season in May/June affected yield more than those developing at seed ripening. As with light leaf spot, this relationship is useful retrospectively, but is of little practical use for growers, as the disease needs to be controlled in the autumn. Sansford *et al*. (1996) suggested that for a two spray autumn programme for canker control to be economic (at a rapeseed price of

£180/t), 34% of stems would need to develop canker by harvest in association with leaf spotting of ≥ 1% before or during January.

From the calculations above losses from stem canker have been estimated at 39 – 282 kt/annum, or £6 – 42 Million/annum (Figure 1) (at a seed price of £150/t) (Fitt *et al*., 1997).

A Phoma forecast, similar to that for light leaf spot, is being developed to predict seasons and sites at high risk from severe Phoma stem canker infection and hence the need for an an autumn fungicide treatment. This forecast is part of the Defra/HGCA LINK PASSWORD (HGCA Project No. 2155; Gladders *et al*., 2004).

Effect of Sclerotinia stem rot on yield

Sclerotinia stem rot (*Sclerotinia sclerotiorum*) is common in parts of France and Germany but severe outbreaks in the UK are sporadic and are generally limited to individual farms (Hardwick *et al*., 1991). From 1987 – 2002, the incidence of Sclerotinia in England & Wales was <5% plant affected, with the exception of 1991 when incidence was slightly above 5% (Fitt *et al*., 1997; Turner *et al*., 2003). In Scotland, Sclerotinia seldom causes problems but each year outbreaks on a few individual farms may be severe.

Sclerotinia is a monocyclic disease. Sclerotia within the surface layers of the soil germinate during April/May to produce apothecia at soil level. Wind-borne ascospores are released from the apothecia and are deposited on petals. Petals fall onto leaves and the ascospores use the dead petals as a source of nutrients. Under optimum conditions of 15-20^{o}C and relative humidity >80% (Heran *et al*., 1999) the fungus initially infects petals before penetrating the leaves and growing down petioles into the stem. Petals must remain in contact with the leaf for a minimum of 48 hours for infection to occur and infection is greatest during wet conditions when a greater number of petals stick to leaves (Heran *et al*., 1999; McCartney *et al*., 2003). The fungal mycelium colonises the stem tissue and fills the stem cavity, producing the typical white bleached stems. Within the stem cavity the mycelium aggregates into white and eventually hard, black sclerotia. Stems and racemes above the point of infection become brittle, ripen prematurely and this results in premature seed shed. Sclerotia are returned to the soil at harvest or if stems shatter. Sclerotia can be harvested with the rapeseed and result in seed contamination and reduced quality. Sclerotia can remain viable in the soil for up to 7 years (Paul & Rawlinson, 1992).

Infection is determined by previous cropping history, a source of inoculum, suitable weather conditions for germination and ascospore release, ascospore release and flowering to coincide, suitable weather conditions for petal fall and deposition/sticking on leaves. In the UK, risk from Sclerotinia is generally determined from cropping history and prevailing weather conditions (Turner *et al*., 2002). In Canada, petal testing is carried out to determine the presence and severity of ascospores on petals (Turkington & Morrall, 1993; Anon, 2004b) but this is seldom used in the UK. Petal testing takes approximately 10 days to complete but a 10 day delay in spraying against Sclerotinia could be the difference between complete control and no control at all (Turner *et al*., 2002).

Using previous cropping as a predictor is not 100% accurate as spores can be carried several kilometres and the most severe outbreaks often occur on farms with no previous history of infection or with very low levels of apothecia present in the soil (Turner *et al*., 2002). Until recently, risk was determined by the previous years' infection; if >20% of plants in a crop the previous season were infected with Sclerotinia then there was a 60% chance of requiring a fungicide spray (Sansford, 1995). However, more recently, spore trapping and epidemiological methods have been used to identify and quantify the presence of ascospores at flowering (McCartney *et al*., 1999a; Turner *et al*., 2002). Sclerotinia infection is favoured by wet or high relative humidity (Heran *et al*., 1999). If conditions at flowering are dry, petals are less likely to stick to leaves and the risk of infection is reduced.

When applied at the correct timing, fungicides can give almost 100% control of Sclerotinia stem rot (Turner *et al*., 2002). The ideal time to apply fungicides is early to mid-flowering, depending on the season. Fungicides applied at late flowering are generally less effective at controlling Sclerotinia but in some seasons these late sprays can be the most effective (Sansford *et al.,* 1996; Turner *et al.,* 2002). Sansford *et al*. (1996) showed that if fungicide sprays were omitted in early spring, this could increase Sclerotinia infection. Yield responses to fungicide applications are frequently not significant or are not cost effective (Sutherland *et al*., 1990) but the risks to following crops such as rape, potatoes, peas, carrots, vegetable brassicas or lettuce are reduced.

Pope *et al*. (1989) found that a Sclerotinia incidence of 6.95% resulted in a reduction in thousand seed weight of 14.3%. In Canada, yield losses are approximately 50% of the incidence, i.e. if 20% plants are affected the yield loss will be 10% (Anon., 2004b). In field trials in Australia, Sclerotinia led to yield losses of 15-23% (Kirkegaard *et al*., 2003). In Germany, yield losses of approximately 0.7 t/ha were estimated from a disease incidence of 50% (Kruger,1984). Kruger showed an almost linear relationship between Sclerotinia incidence and yield loss; for every 1% increase in Sclerotinia incidence there was a yield loss of 0.014 t/ha. Sansford *et al*. (1996) found similar relationships in the UK; for every 1% of plants with disease on the main stems and racemes there was a yield loss of 0.016 t/ha. From these yield loss correlations Fitt *et al*. (1997) estimated yield losses in the UK from Sclerotinia infection of 0.8-36 kt/annum or £0.12–5.4Million/annum (Figure 1) (based on a seed price of £150/t). Although Sclerotinia reduced harvested yield and Thousand Grain Weight (TGW) it has no effect on the oil content of the seed (McCartney *et al*., 1999b).

Effect of Alternaria dark leaf and pod spot on yield

In the mid-1980s Alternaria dark leaf and pod spot (*A. brassicae* and *A. brassicicola*) was considered the most important disease of oilseed rape in the UK (Ward *et al*., 1985) and has the potential to cause high yield losses. Severe outbreaks in the UK, however, are limited to individual crops. In recent years severe outbreaks in Scotland have been limited to individual crops of spring oilseed rape.

Alternaria can infect crops either via seed-borne infection or from wind-borne condiospores produced on the previous years' stubble and trash (Paul & Rawlinson, 1992). Symptoms may appear in the autumn as small (2-5 mm) dark spots on leaves but the disease often disappears over winter to return in late spring and early summer. Later infections appear on upper leaves and bracts, upper stems and pods. Leaves often show typically large 'target spot' lesions with alternate rings of dark and pale brown tissue surrounded by a yellow halo. Upper stems and racemes develop round to elongated purplish brown lesions and pods show typical dark brown/black shiny spots. Pod infections cause premature ripening and pods shatter causing severe seed shedding pre- and during harvest. Oilseed rape volunteers are a major problem in following crops and herbicide costs are increased.

Infections are favoured by high temperatures (17-25^{o}C) and high relative humidity (Paul & Rawlinson, 1992), conditions that can build up rapidly in crops during pod ripening and within lodged crops approaching harvest. Fungicide application during pod formation is difficult as pod density and lodging can prevent penetration of fungicide sprays. Also, specialist high clearance sprayers are required which can themselves cause crop damage and reduce yield. Reducing the risk of lodging by growing shorter varieties, and using growth regulators can reduce the risk of Alternaria infection. Disease infection is also limited by the presence of leaf wax and breeding varieties with thicker leaf wax reduces the risk of infection.

Alternaria is controlled by fungicide seed treatments and foliar fungicides applied post-flowering. In 1987 the incidence of Alternaria pod spot in crops in England & Wales was 88% crops and 53% plants affected, with approximately 41% of crops receiving a post-flowering spray (Defra-funded Survey). By 1995 disease incidence was around 7% plants affected, with <10% crops sprayed. Since this time, however, the number of crops sprayed has remained at a steady level of around 5% despite disease incidences in 1998-2000 and 2002 ranging from 31.5 – 62.6% (Turner *et al*., 2003), an indication that growers now perceive Alternaria to be of little importance. However, epidemics of this disease can explode within a few weeks and growers should not become complacent.

In Germany, yields are only affected if >5% of the pod area is infected with Alternaria (Hardwick *et al.*, 1991). In seasons of early and severe attacks of Alternaria, yield losses of 20-25% are not uncommon (Ward *et al*., 1985). Gladders (1988) estimated for every 1% pod area infected with Alternaria there was a yield loss of 1%. From these calculations Fitt *et al*. (1997) estimated yield losses from Alternaria in the region of 0.14-7.5 kt/annum or £0.02-1.12 Million/annum (Figure 1) (at a seed price of £150/t).

References

Anon. (2004a) Oilseed crop pathogens and pests – light leaf spot of winter oilseed rape *(Pyrenopeziz brassicae*). http://www.rothamsted.bbsrc.ac.uk/ppi. 16 January 2004.

Anon. (2004b) Canola diseases in British Columbia. Sclerotinia stem rot. http://www.agf.gov.bc.ca/croprot. 14 May 2004.

Baierl, A., Evans, N., Steed, J.M., Fitt, B.D.L. & Sutherland, K.G. (2002) Effects of light leaf spot (*Pyrenopeziza brassicae*) infection on winter survival and yield of oilseed rape (*Brassica napus*). *Proceedings of the BCPC Conference – Pests & Diseases*, pp 629 – 634.

Biddulph, J.E., Fitt, B.D.L., Leech, P.K., Welham, S.J. & Gladders, P. (1999) Effects of temperature and wetness on infection of oilseed rape leaves by ascospores of *Leptosphaeria maculans* (stem canker). *European Journal of Plant Pathology* **105**, 769 – 781.

Fitt, B.D.L., Gladders, P., Turner, J.A., Sutherland, K.G., Welham, S.J. & Davies, J.M.L. (1997) Prospects for developing a forecasting scheme to optimise use of fungicides for disease control on winter oilseed rape in the UK. *Aspects Applied Biology* **48**, 135-142.

Gladders, P. (1988) The contribution and value of pesticides to disease control in combinable break crops. In *Control of Plant Diseases: Costs and Benefits*, pp 29-50. Eds. B.C. Clifford and E. Lester. Oxford: Blackwell Scientific Publications.

Gladders, P & Musa, T.M. (1980) Observations on the epidemiology of *Leptosphaeria maculans* stem canker in winter oilseed rape. *Plant Pathology* **29**, 28 – 37.

Gladders, P., Fitt, B.D.L. & Turner, J.A. (1999) Improving strategies to control canker in the UK. *Proceedings of the 10th International Rapeseed Congress*, Canberra. CD-Rom.

Gladders, P., Green, M.R., Steed, J.M., West, J.S & Fitt, B.D.L (2001) Improving stem canker control in winter oilseed rape by accurate timing of fungicide applications based on disease forecasts. HGCA Project Report No. OS51, 115 pp. HGCA, London.

Gladders, P., Symonds, B.V., Green, M., Ottoway, C.J. & Hardwick, N.V. (1998) Development of appropriate fungicide dose strategies for control of canker (*Leptoshearia maculans*) in winter oilseed rape. *Proceedings 1998 International Congress of Plant Pathology*, Abstract 4.9.9.

Gladders, P., Dyer. C., Fitt, B.D.L., Evans, N., Van den Bosch, F., Steed, J.M., Baierl, A., Turner, J., Walters, K., Northing, P., Sutherland, K., Campbell, C., Ellerton, D., Selley, A., Hall, B., Naylor, D. & Parker, C. (2004) Pest and disease management system for supporting winter oilseed rape decisions (PASSWORD). *SAPPIO LINK Project Report No. 2155*, 255 pp. Defra/HGCA, London. (In Press).

Hammond, K.E. & Lewis, B.G. (1986) The timing and sequence of events leading to stem canker disease in populations of *Brasica napus* var. *oleifera* in the field. *Plant Pathology* 35, 551-564.

Hardwick, N.V. (1987) Winter oilseed rape: survey of diseases 1987. ADAS Report

Hardwick, N.V., Culshaw, F.A., Davies, J.M.L., Gladders, P., Hawkins, J.H. & Slawson, D.D. (1989) Incidence and severity of fungal diseases of winter oilseed rape in England and Wales, 1986-88. *Aspects of Applied Biology* **23**, 383-392.

Hardwick, N.V., Fitt, B.D.L., Wale, S.J. & Sweet, J.B. (1991) Oilseed rape diseases. *HGCA review article*, 113 pp. HGCA, London.

Heran. A., McCartney, H.A. & Li, Q. (1999) The effect of petal characteristics, inoculum density and environmental factors on infection of oilseed rape by *Sclerotinia sclerotiorum*. *Proceedings 10th International Rapeseed Congress*. Canberra. CD-Rom.

Jeffrey, I.G., Cutler, J.R. & Brodie, J. (1983) Pesticide usage in Scotland. Oilseed rape 1981-1982. *Survey Report* **44**, 15 pp. DAFS, Edinburgh.

Kirkegaard, J., Robertson, M., Barber, M., Wright, J. & Hamblin, P. (2003). Limits to achieving potential yield of canola in southern NSW. *Proceedings 11th Australian Agronomy Conference*, Geelong, 2003. http://www.regional.org.au/au/asa/2003/p/3/. 14 May 2004.

Kruger W. (1984) *Oilseed rape pests and diseases*. 119 pp. Semundo, Hamburg.

McCartney, H.A., Lacey, M.E., Li, Q. & Heran, A. (1999a) Airborne ascospore concentration and the infection of oilseed rape and sunflowers by *Sclerotinia sclerotiorum. Proceedings 10th International Rapeseed Congress*. Canberra. CD-Rom.

McCartney, H.A., Doughty, K.J., Norton, G., Booth, E.J., Kightley, S.J.P., Landon, G., West, G., Walker, K.C & Thomas, J.E (1999b) A study of the effects of disease on seed quality parameters of oilseed rape. *Proceedings 10th International Rapeseed Congress*. Canberra. CD-Rom.

McCartney, H.A., Heran, A., Li, Q., Freeman, J. & Foster, J. (2003) Petal fall, petal retention and petal duration in oilseed rape crops. *Proceedings 11th International Rapeseed Congress*, pp1084-1086. Copenhagen.

Paul, V.H. & Rawlinson, C.J. (1992) *Diseases and pests of rape*. Verlag Th.Mann, Gelsenkirchen-Buer. 132 pp.

Pope, S.J., Varney, P.L. & Sweet, J.B. (1989) Susceptibility of cultivars of oilseed rape to *Sclerotinia sclerotiorum* and the effect of infection on yield. *Aspect of Applied Biology* **23**, 451-456.

Rawlinson, C.J., Muthyalu, G. & Cayley, G.R. (1984) Fungicide effects on light leaf spot, canker, crop growth and yield of winter oil-seed rape. *Journal of Agricultural Science* **103**, 613–628.

Sansford, C. (1995) A sensible approach to Sclerotinia control. *The Adviser*, Spring 1995. pp 36

Sansford, C.E., Fitt, B.D.L., Gladders, P., Lockley, K.D. & Sutherland, K.G. (1996) Oilseed rape: development, forecasting and yield loss relationships. *HGCA Project Report No. OS17*, 185pp. London:HGCA.

Snowden, J.P., Bowen, H.M & Dickson, J.M. (1991) Pesticide usage in Scotland. Arable Crops 1988.

Survey Report 77, 83pp. Edinburgh:SOAFD.

Su, H., Fitt, B.D.L., Welham, S.J., Sansford, C.E. & Sutherland, K.G. (1998) Effects of light leaf spot (*Pyrenopeziza brassicae*) on yield of winter oilseed rape (*Brassica napus*). *Annals Applied Biology* **132**, 371-386.

Sun, P., Fitt, B.D.L., Gladders, P. & Welham, S.J. (2000) Relationships between Phoma leaf spot and development of stem canker (*Leptosphaerai maculans*) on winter oilseed rape (*Brassica napus*) in southern England. *Annals of Applied Biology* **137**, 113-125.

Sutherland, K.G., Booth E.J. & Walker, K.C. (2004) Effects of added sulphur on fungicide control of light leaf spot. Project Report No. 326, HGCA, London.

Sutherland, K.G., Evans, N., Fitt, B.D.L., Morgan, D., Northing, P., Turner, J.A., Walters, K.F.A. & Parker, C. (2002) Development of a DSS for diseases and pests in winter oilseed rape. *Proceedings Crop Protection in Northern Britain 2002*, pp 163 –168. Dundee.

Sutherland, K.G., Oxley, S.J.P, Brokenshire, T & Munro J.M. (1990) The control of late disease of winter oilseed rape in Scotland. *Proceedings 1990 Brighton Crop Protection Conference – Pests & Diseases*, pp 789-794.

Sutherland, K.G, Wale, S.J. & Sansford, C. (1995) Effect of different epidemics of *Pyrenopeziza brassicae* on yield loss in winter oilseed rape. *Proceedings 9th International Rapeseed Congress*, pp 1004-1006. Cambridge.

Turkington, T.K. & Morrall, R.A.A. (1993) Use of petal infestation to forecast Sclerotinia stem rot of canola: The influence of inoculum variation over the flowering period and canopy density. *Phytopathology* **83**, 682-689.

Turner, J.A., Elcock, S.J., Gladders, P., Walters, K.F.W., & Wright, D. (2000a) Winter Oilseed Rape: Surveys of Pests and Diseases 1990.2000. CSL/ADAS Report.

Turner, J.A., Elcock, S.J., Hardwick, N.V. & Gladders, P. (2000b) Changes in fungicide use in England and Wales during the 1990's. *Proceedings BCPC Conference, Pests & Diseases 2000*, pp 865-870. Brighton UK.

Turner, J.A., Elcock, S.J. & Gladders, P. (2003) Effective control of oilseed rape diseases in the UK – challenges and threats. *Proceedings 11th International Rapeseed Congress*, pp1120-1222. Copenhagen.

Turner, J.A., Young, C., Riding. A & Gladders, P. (2002) Sclerotinia control in oilseed rape: progress with quantitative diagnosis and development of a web-based forecasting scheme. *Project Report No OS56.* 71 pp. London:HGCA.

Wale, S.J., Brokenshire, T., Oxley, S., Sutherland, K. & Munro, J.M. (1990) Fungicidal control of light leaf spot (*Pyrenopeziza brassicae*) on oilseed rape in Scotland. *Proceedings Crop Protection in Northern Britain Conference* 1990, pp 289-294. Dundee.

Ward, J.T., Basford, W.D., Hawkins, J.H. & Holliday, J.M. (1985) *Oilseed rape*. 298 pp. Ipswich:Farming Press Ltd.

Welham. S.J., Turner, J.A., Gladders, P., Fitt, B.D.L., Evans, N. & Baierl, A. (2004) Predicting Light Leaf Spot (*Pyrenopeziza brassicae*) risk on winter oilseed rape (*Brassica napus*) in England & Wales, using survey, weather and crop information. *Plant Pathology* (In Press).

West, J.S., Biddulph, J.E., Fitt, B.D.L. & Gladders, P. (1999) Epidemiology of *Leptosphaeria maculans* in relation to forecasting stem canker severity on winter oilseed rape in the UK. *Annals of Applied Biology* **153**, 535-545.

Zhou, Y., Fitt, B.D.L., Welham, S.J., Gladders, P., Sansford, C.E. & West, J.S. (1999) Yield loss of winter oilseed rape in relation to severity of stem canker (*Leptosphaeria maculans*) in the UK. *Proceedings 10th International Rapeseed Congress, New Horizons for an old Crop*. 4 pp. CD-Rom. Canberra, Australia.